U.S. Army Corps of Engineers
Walla Walla District

Fish Individual-based Numerical Simulator (FINS) Model

Final Report

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1 Executive Summary

This report summarizes the continued development and application of the Fish Individual-Based Numerical Simulator (FINS) model. FINS describes the movements of individual simulated juvenile salmonids during their outmigration from the Snake and Columbia rivers. Increased understanding of the movement of individual fish is critical to determining the effects of river conditions and operations on the success of smolt migration. In particular, we focus here on describing the exposure histories of individual fish to supersaturated levels of total dissolved gas. The effects of dissolved gases on smolt viability cannot be well represented by bulk average or population-based measures, since the effects of cumulative exposure and fish behavior on swimming ability and mortality are significant. Individual-based models such as FINS are also applicable to the study of biological effects of other migration factors such as water temperature, turbidity, or predation.

The FINS model was initially developed by Battelle under a previous contract with the U. S. Army Corps of Engineers, Walla Walla District. Under the current work order, several enhancements have been made to the model, including porting the code to a Unix platform and development of a web interface. The primary focus of the work reported here was the analysis of fish tracking data to validate the FINS approach and develop meaningful model parameterizations. FINS was first applied to simulate inter-dam travel times as observed from PIT tag data. Although PIT tag data does not provide detailed (within-reach) information on the movement of individual fish, it proved useful for motivating further study of autocorrelation in fish migration behavior. Detailed information on the movements of individual fish was made available by the U. S. Geological Survey (Biological Research Division) in the form of radiotelemetry observations collected during the 1997 and 1998 out-migration seasons. This information was used in conjunction with a quasi-inverse version of FINS to separate out the relative effects of advection (movement with local water velocity) and active fish swimming (represented as dispersive displacements in the FINS model). It was clearly demonstrated that temporal autocorrelation exists in the fish swimming behavior, and must be accounted for when interested in individual fish movements. A correlated random-walk model was developed and parameterized based on the radiotelemetry data. We also validated and parameterized the FINS depth-variation model based on the radiotelemetry data, subsequently demonstrating that a linear depth preference model with random fluctuations was representative of the detailed 1-minute fish observations.

Example runs of the FINS model were made for four cases in the McNary pool (from Ice Harbor tailrace to McNary forebay): (1) 1997 hatchery spring chinook (HSPC), (2) 1997 hatchery steelhead (STHD), (3) 1998 HSPC, (4) 1998 STHD. The results of each example run, using only 25 simulated fish for ease of presentation, were graphically summarized. A single larger run (simulating 1000 individual fish) was also made to demonstrate the capability of the code to develop statistical summaries of the behaviors and exposure histories of large numbers of individual simulated fish. The linkage between hydrodynamic simulations of river flow (on which FINS simulations are based) and observations of local fish movement patterns (from radiotelemetry data) has been established using the FINS model. The ability of FINS to distinguish the effects of river advection from the effects of fish swimming was demonstrated, and a viable correlated random walk model of fish behavior has been developed. Species- and migration-year-specific model parameters were derived for two years and two species, for a selected river reach. Example runs of

the FINS model reproduce observed features of fish migration in that reach, and demonstrate the potential value of FINS as a biological management tool in the Columbia River basin.

2 FINS Model Description

2.1 Project Objectives

The Fish Individual-based Numerical Simulator (FINS) model is a discrete, individual-based model that simulates the downstream migration of juvenile salmonids (smolts) during their out-migration. ”Individual-based” refers to the simulation of individual fish as objects or ”particles” within the transport system, as opposed to more common lumped-parameter models that simulate distributions of fish populations as a whole while not specifically representing individual fish. FINS was developed primarily for the purpose of evaluating the biological effects of exposure to supersaturated levels of dissolved gas. These effects depend on the long-term exposure history of individuals, not the average exposure level of a group of individuals, and therefore their evaluation requires an individual-based approach. FINS is also applicable to a number of other problems related to the survival of individual fish during out-migration, such as predation, reservoir passage processes, and temperature exposure.

FINS links physical/hydrodynamic models that describe the environmental conditions (i.e. flow depth, velocity, temperature and gas saturation) in river systems, and biological models that relate fish health and mortality to the environmental conditions that fish experience. FINS utilizes as input two-dimensional distributions of local water velocity, depth, dissolved gas level, and temperature generated by the hydrodynamic model MASS2, and provides as output gas exposure and depth histories of individual fish (the number of individuals simulated is specified by the user).

The FINS model has been applied primarily to fish migrating from Ice Harbor Dam on the Snake River to the forebay of McNary Dam on the Columbia River. The focus of work in the past year has been on the analysis of fish tracking data for the purpose of evaluating FINS performance and developing meaningful model parameters. Effort has also been given to the development of a web interface to FINS, porting FINS to a Unix platform, and enhancing certain aspects of the code.

2.2 Processes Simulated in FINS

Because the hydrodynamic model MASS2 is two-dimensional (vertically averaged), there are two groups of processes simulated independently in FINS: 1) downstream and lateral movements of individual fish, and 2) vertical movements of individual fish.

2.2.1 Downstream and Lateral Fish Movements

Smolt movements in the horizontal plane (downstream and across-channel) are represented in FINS in terms of four general processes:

1. Advection: Passive movement with the local water velocity

2. Dispersion: Random variations in fish velocity (differing from local water velocity) that are linearly related to local water velocity. This represents the apparent effects of water velocity variations at scales smaller than that explicitly modeled in the hydrodynamic simulation.

3. Diffusion: Random variations in fish velocity (i.e. deviations from local water velocity) that are unrelated to local water velocity. This represents random velocity variations due to fish swimming and allows fish to move out of low velocity areas that they would otherwise be ”stuck” in.

4. Correlated Random-Walk: Both the diffusion and dispersion mechanisms are uncorrelated in space and time. However, it is reasonable to imagine that if a fish is swimming faster than the local water velocity at one time, it will probably still be doing so at the next time step. This is represented in the correlated random-walk model by a probabilistic correlation between the random velocity variations from one time step to the next.

The dispersion and diffusion processes are combined into a single diffusion-like process, where the effective diffusion coefficient is the sum of the specified diffusion coefficient and the product of the specified dispersivity and the local water velocity.

The advection process does not require any parameterization, since it is purely determined by the local water velocities as computed in the hydrodynamic code. The dispersion process is parameterized by the ”dispersivity” α (ft). The value of α, since it represents sub-grid- scale velocity variations, should theoretically be smaller than the average grid spacing. The diffusion process is parameterized by the ”diffusion coefficient” (ft^2/sec). The overall dispersion coefficient D is obtained by combining the dispersivity and diffusion coefficient as follows:

$$D = D' + \alpha V \tag{2.1}$$

Where D' is the specified diffusion coefficient, α is the dispersivity, and V is the local water velocity.

In the fish transport algorithm, the diffusive displacement (dx) in any given time step is defined by

$$dx = (U_I - 0.5)(24.0 * D * dt)^{1/2} \tag{2.2}$$

where dt is the time step in seconds and U_I is a pseudo-random number uniformly distributed between 0 and 1.

The values of the dispersivity and diffusion coefficients are specified in terms of lateral (parallel to local flow direction) and transverse (perpendicular to local flow direction) components and are generally species-dependent.

The correlated random-walk process allows for greater overall dispersion (spreading out of fish particles) without imposing excessively large displacements in any single time step. It uses the specified values of dispersivity and diffusion coefficient as in the standard approach, but uses correlated random number sequences to compute the actual displacements in each time step. Correlated random number sequences can be generated in a number of different ways. Two alternative approaches used here are described in Chapters 2 and 3.

2.2.2 Vertical Fish Movements

The hydrodynamic simulation is depth-averaged, two-dimensional. Therefore, modeled water velocity varies only in the plan view coordinates and cannot be used to drive changes in smolt depth. Three alternative processes have been implemented to allow variations in smolt depth (which in turn affects the depth-compensated total gas pressure even though dissolved gas concentrations do not vary vertically in the model). These three processes are:

1. *Linear preference model:* This model assumes that smolts are generally surface-oriented and have a specific preferred migration depth (distance from the water surface). This function provides a ”driving force” to move fish toward the preferred depth at a rate that depends linearly on their current deviation from that depth. Note that this model does not provide any means of moving away from the preferred depth, so if used alone will lead to a constant smolt depth equal to the preferred depth (once the initial release conditions have been overcome). This model is parameterized by two parameters: 1) the preferred depth (in feet), and 2) the linear preference coefficient that scales the vertical velocity as a function of deviation from the preferred depth.

2. *Exponential preference model:* This model is similar to the linear preference model, but assumes that the strength of the vertical velocity toward the preferred depth is an exponential function of the deviation. This model is along the lines of that derived from principles of light dissipation with depth and preference of smolts for a particular level of light (see Zabel (1994)). This model has three parameters: 1) the preferred depth (in feet), 2) a constant coefficient, and 3) an exponent. See Anderson et al. (1998) for details. Again, this model alone will not lead to any variation in depth.

3. *Random vertical velocity model:* This model uses random vertical velocities generated in each time step. It is parameterized by a mean vertical velocity (drift), generally taken as zero, and a variance in vertical velocity. Random vertical velocities are assumed to be normally distributed, with the specified mean and variance. This model will usually be combined with models 1 or 2 above to generate random movements about a preferred depth, but can also be used alone to generate a purely random depth history.

2.3 Model Implementation

The original version of FINS was implemented in FORTRAN 90 for Windows platforms, using the Digital FORTRAN compiler. Subsequently, to facilitate Web access, increase execution speed, and eliminate dependence on compiler-specific libraries, FINS was ported to a UNIX platform, again using FORTRAN 90.

A preprocessor (”Initial”) was developed for the generation of the initial fish locations and times according to spatial and temporal distributions specified by the user. A postprocessor (”Post-Pro”) was also developed to generate statistical summaries of individual fish exposure and depth histories. Both of these codes also are compiled in FORTRAN 90 on Unix platforms.

In general, FINS is executed manually on the host Unix system, and execution control is via a number of input and configuration files. However, the web-based graphical interface described below has also been developed for FINS. Specific information on the requirements of input and configuration files, and a description of the process involved in running the FINS model, is provided in the Appendix.

2.4 FINS Modifications

The original version of FINS was developed during fiscal year 1998. Under the current delivery order (Delivery Order 9), modifications to the FINS code were made in five general areas:

2.5 Web Interface

A web-based interface to FINS has been developed to facilitate use of FINS by non-experts, and to support a distributed user base. The interface utilizes the standard Common Gateway Interface (CGI) and a series of scripts written in the Perl language to guide the user through a series of screens. Each screen contains forms that allow the user to set up the configuration and input files without having to deal with details of file formats. A library of pre-executed hydrodynamics output files from MASS2 is available on half-hour intervals for selected time periods, for use as input by web users of FINS. This system allows remote users with minimal computer expertise to execute FINS on the host computer at the Pacific Northwest National Laboratory and obtain simulation results from any computer with Internet access. The FINS Web Interface can be accessed from the FINS website at http://etd.pnl.gov:2080/FINS/.

2.6 Inter-Pool Connectivity

The current version of FINS simulates fish migration from a release point (typically in or near the tailrace of an upstream dam) to the forebay of the next dam downstream. Movement of fish through the entire river system requires a method of transferring simulated fish from one pool to the next (that is, from the forebay of a dam to the tailrace), e.g., dam passage. Dam passage is a complex process that has been studied in extensive detail from a variety of perspectives, and full simulation of this process is beyond the scope of the current effort. However, here we outline a general strategy that could be used, with varying levels of sophistication depending on available information, to perform river-wide simulations with FINS.

A series of individual pool simulations with FINS can be directly performed using the existing version by using the ”fish file” generated as output from the upstream pool as the input conditions for the next downstream pool. By simply changing the ”x” (river mile) coordinate in the output fish file from 1.0 (which represents the downstream end of a grid reach) to 0.0 (which represents the upstream end of the next grid reach), the simulated fish would be moved across the dam at the instant it arrived at the forebay and at the same lateral (”y” coordinate) position. The output from the upstream pool, with this simple modification, could then be used directly as the input for a simulation in the downstream pool. A number of enhancements to this process, to make it more physically/biologically realistic, are possible given sufficient information. These enhancements are not currently coded in FINS due to their complexity and project specificity, but are briefly outlined here.

For example, it is known that there is some migration delay associated with dam passage. That is, juvenile fish do not enter their selected passage route immediately upon reaching the dam forebay, but rather tend to mill about for a time before passing the dam. A statistical event time model, such as a Poisson process, would be appropriate for representing the distribution of individual passage delay times, and might be parameterized based on forebay radiotelemetry observations.

Passage route is another important consideration, since the passage route selected will govern the location of the fish in the tailrace after dam passage (and therefore its initial location in the simulation of the downstream pool). Hydroacoustic studies performed at several dams have provided information regarding the percentage of migrants using various passage routes (spillway, powerhouse, and bypass) as a function of operational conditions (percent spill, total flow, etc.).

These could be used to assign a fraction of simulated fish to each passage route; individual fish would be assigned at random according to the specified proportions. If sufficient information were available, the probability of assignment of a given individual to a particular passage route might also be dependent on the location (depth and laterally) at which the simulated fish arrives at the forebay.

These processes should be implemented as an external code to FINS, similar to the existing preprocessor ”Initial” that sets up initial fish locations and times. This post-/pre- processor would take as input the locations and times of simulated fish as they arrive at the forebay (as currently written as output of FINS), and output their initial times and locations in the subsequent river reach (as currently used as input for FINS). Thus, the fish file as currently used in FINS would serve as the data format for accomplishing the transfer.

3 Travel Time Analysis and Correlated Random Walk

3.1 Introduction

Most discrete implementations of advective/dispersive transport utilize an *uncorrelated* random walk model that corresponds to the continuum Fickian diffusion model in which the rate of diffusive mass transfer depends linearly on the concentration gradient. This model is applicable to systems such as molecular diffusion, and describes the large-scale (macroscopic) effects of very small-scale movements (e.g., molecular movements and collisions) that can be considered fully random (independent and identically distributed) at the macroscopic scale.

However, if in fact swimming behaviors of individual fish are persistent over significant time scales, the assumptions of such a model are invalidated. In such a case, a *correlated* random walk model may be more appropriate. In this chapter, we utilize travel time observations derived from Passive Injected Transponder (PIT) fish tracking data to examine whether the purely random motion model appropriately describes variability in individual movements, or if a correlated random walk may be more appropriate.

3.2 Description of PIT data

PIT tags are small transmitters that are emplaced in the body cavity of migrating smolts. These transmitters are activated when passing through specific interrogation facilities, located in juvenile bypass routes at several dams on the Columbia and Snake rivers. Each tag has a unique label, allowing the determination of travel times of individual fish from one dam to the next by comparison of observation times.

PIT tag observation data files from the 1996 smolt migration season were downloaded from the Pacific States Marine Fisheries Commission (PSMFC); see http://www.psmfc.org/ for more information. The raw data files contain one record per line, each record representing an observation of an individual fish at a specific interrogation point (dam). Because no interrogation facility existed at Ice Harbor Dam, we considered fish that were observed at both Lower Monumental Dam (LMN) – the next project upstream of Ice Harbor – and McNary Dam (MCN). A series of computer scripts were used to extract selected records from the full PIT tag dataset. Here we consider Hatchery Spring Chinook observed at both LMN and MCN during the 1996 migration season. Field crews observed 2013 individual fish at each of the LMN and MCN interrogation points.

3.3 Lumped-Model Parameterization and Fit to PIT observations

The estimation of parameters for FINS based on observed fish movements cannot be easily performed directly. Instead, we must use either a trial-and-error calibration approach or a quasi inverse-modeling approach (as described in Chapter 3). However, the distribution of travel times can be used to directly estimate parameters representing the mean and variability of individual travel times in a continuum lumped-parameter model. Since a loose relationship exists between the continuum model and its discrete form as represented in FINS, this is a useful exercise.

Zabel [1994, p.52] provides maximum likelihood estimators for the mean advective velocity r and the variability in fish travel times (σ). Application of these to the distribution of travel times derived from the 1996 PIT observations described above gives values of $r = 27.21 km/day$ and $\sigma = 24.78 km/day^{1/2}$, which are consistent with the range of estimates reported by Zabel [1994, Table 4.2, p. 69].

The corresponding arrival time distribution is given by Zabel [1994, p. 49] as:

$$g(t) = \frac{L}{\sqrt{2\pi\sigma^2 t^3}} \exp\left(\frac{-(L-rt)^2}{2\sigma^2 t}\right) \tag{3.1}$$

Where L is the distance between upstream and downstream observation points. The distance from Lower Monumental to McNary dams is 129 kilometers or approximately 423,230 feet.

In our formulation of the advection-diffusion equation, the parameter D' corresponds to $\sigma^2/2$ in Zabel's equation 4.3. Therefore, we estimate $D = 3.30 * 10^9 ft^2/day$. If we consider only the velocity-dependent portion of D, we get $D = \alpha V$, where V is the mean velocity and α is the dispersivity. This gives a value for α_L of approximately 37,000 feet. Note that this is only the longitudinal component of dispersivity; no estimate of transverse dispersivity can be obtained from PIT data.

The distribution of smolt travel times predicted by the continuum advection-dispersion model can be computed and compared to the actual histogram of arrival time data. Although we have not performed a rigorous model test, the travel-time observations and the continuum travel-time model visually appear to conform quite well (Figure 3.1).

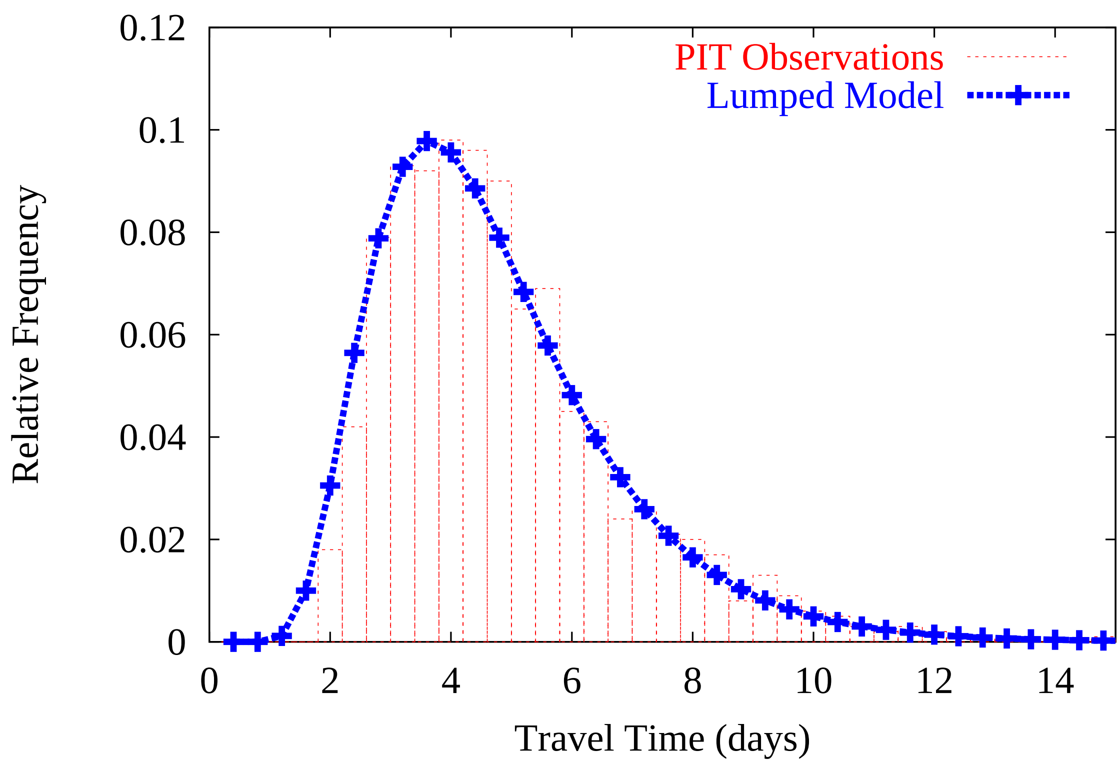

Figure 3.1: Comparison of predicted smolt travel times with arrival time data for the 1996 Hatchery Spring Chinook (bars = data; line/symbols = model).

3.4 Equivalent Individual-Based Model Fit to PIT observations

If FINS used a mean flow velocity independent of spatial location and the uncorrelated random walk method, the travel time distribution resulting from FINS for the parameters above should theoretically be identical to those resulting from the continuum model (assuming a sufficient number of fish particles were simulated). However, in the FINS model, the average rate of fish migration (r in the continuum model) is not specified as a model parameter. Instead, fish move with the local flow velocity, as provided by the hydrodynamic model results. There is an ensuing mean migration rate for any particular simulation run, but it results from the combined effects of all the local velocities experienced by each fish, rather than being specified *a priori*. However, the dispersion is modeled using a random-walk procedure, and therefore an *a priori* estimate of α is required. Some of the variability reflected in the estimate of α above, however, will be explicitly accounted for by virtue of variable local velocities; therefore we expect that the appropriate value of α to use in the FINS model will be something smaller than that derived directly from the PIT data. The FINS model was executed (using the uncorrelated random walk) using trial values of α, and the results were compared to the lumped model prediction that incorporated the parameters derived from the PIT data as well as the PIT data histogram itself, therefore providing a test of the FINS model parameterization against the PIT tag observations.

Flow conditions input to FINS were from the hydrodynamic model simulation corresponding to noon on July 8, 1996. Combined ”dispersion” and ”diffusion” effects were simulated with parameters as follows:

α_L	1000	ft
α_L	100	ft
D_L	1000	ft^2/sec
D_L	100	ft^2/sec

As indicated in Figure 3.2, the model is unable to reproduce the degree of variability in travel times observed in the PIT tag data using these parameters.

Attempts to run FINS with larger values of α resulted in model crashes. We determined that the reason for the code failure was that simulated fish were crossing multiple sub-reach grid boundaries in a single time step (which was not allowed by the code). Since these sub-reaches are spatially extensive (kilometers) and the time steps utilized are small (50 seconds typically), such occurrences are physically and biologically implausible. In fact, values of $\alpha = 1000\,ft^2/sec$ and $D_L = 1000$ ft/sec (assuming mean flow velocity of 1 ft/sec) can be shown to lead to a maximum displacement of 1100 feet in 50 seconds, which would require a sustained swimming velocity of over 20 ft/sec. And even under these intuitively unrealistic conditions, the simulated results do not have the degree of variability required to match the PIT tag observations. We conclude, therefore, that while a 1D lumped-parameter model based on a simple advection- diffusion approach can reproduce observed travel time distributions well in a population sense, the individual behavior implied by this model is entirely unrealistic. This also indicates that the uncorrelated random walk model in FINS is a poor representation of individual behavior.

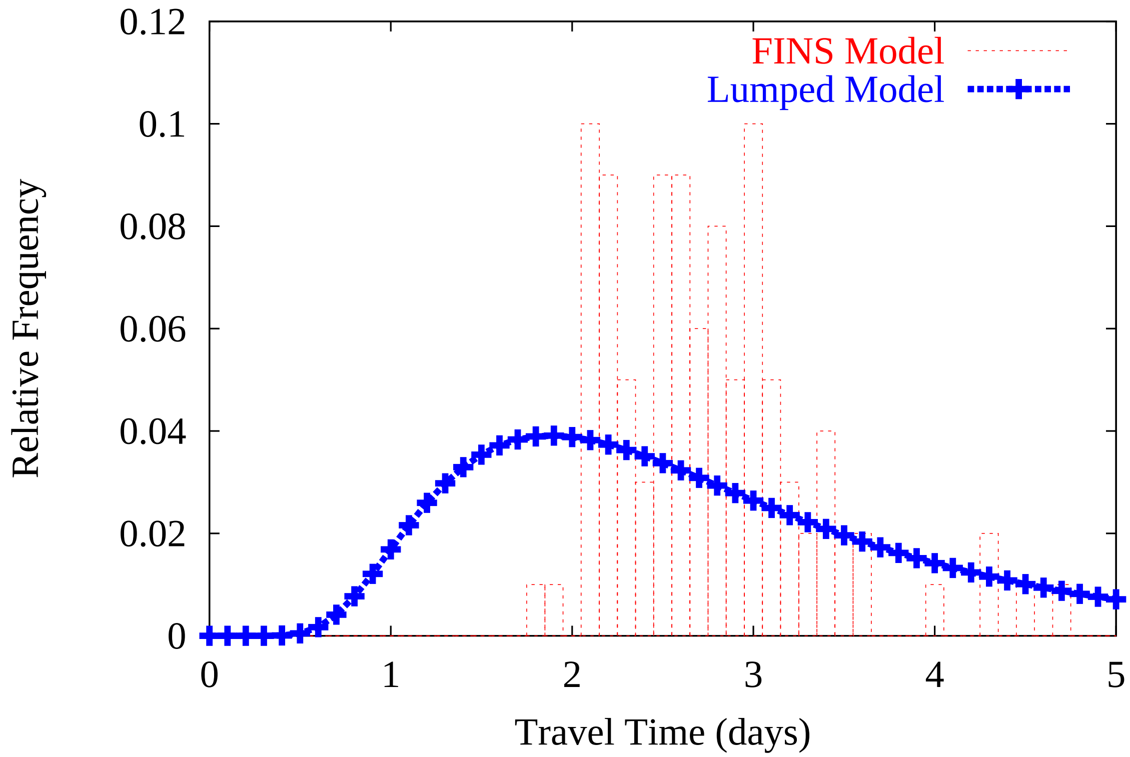

Figure 3.2: Comparison of travel times predicted using FINS (uncorrelated random walk) with those predicted using the 1D lumped-parameter model with parameters estimated from the PIT tag data (see Figure 3.1)

3.5 Correlated Random Walk Model

In the correlated random-walk approach, the dispersive component of migration at any particular time step is correlated to that in the previous time step. This is intuitively sensible, since a fish moving fast relative to flow in one time step is likely to continue in the same manner in the next time step (and vice versa). This also should result in larger variations in long-term travel times between individuals for the same magnitude of local variations, because the effects of the individual displacements are additive over time rather than canceling out as is the case for purely random displacements.

FINS allows the user to select whether to use a correlated or uncorrelated random walk method. The correlated and uncorrelated methods are identical, except for the sequence of pseudo-random numbers used for the dispersive process. The method used in this case to introduce correlation is:

$$r_i = r_{i-1} + a(x_i - 0.5) \tag{3.2}$$

where r_i represents the sequence of random numbers to be generated, x_i is a uniform pseudo-random variate on the interval [0,1] (as in the uncorrelated method), and a is a parameter that controls the degree of correlation. Intuitively, a represents the degree of change in the random number allowed from one time step to the next. If a = 1, the maximum possible change is 0.5; if a is zero, the sequence is perfectly correlated. This approach is along the lines of a first-order mixed autoregressive-moving average (ARMA) model (e.g., Payne (1982), p. 201). In this implementation, the values of are further constrained to the interval [0,1] by truncating any values outside that range. Example correlated random number sequences generated using a=0.1 are shown in Figure 3.3.

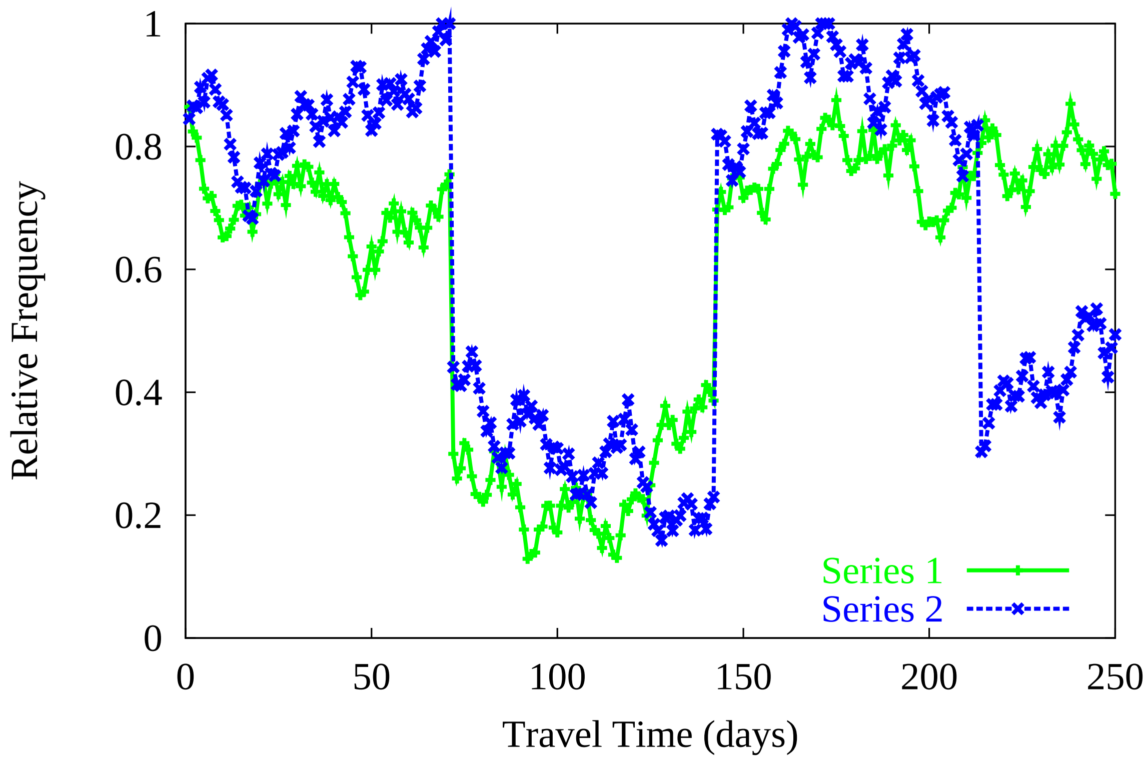

Figure 3.3: Sequences of correlated random numbers generated using a=0.1 (large jumps indicate the beginning of a sequence for a new fish particle)

For comparison, example uncorrelated random number sequences are shown in Figure 3.4.

The same test case described in the above sections was rerun, but this time using a correlated sequence of random numbers with $a = 0.1$ and a much smaller overall dispersion coefficient was set to a value of 75 ft^2/sec (corresponding to a maximum fish sustained swimming velocity of 3 ft/sec), divided between velocity-dependent ($\alpha_L = 25 ft^2/sec$) and velocity-independent ($D_L = 50 ft^2/sec, V = 1 ft/sec$) components. Again, note that these values are much smaller than the values used above to try to match the PIT tag data, and lead to physically plausible maximum swimming velocities.

The modeled arrival distribution from FINS using the correlated random walk method (Figure 3.5) offers a substantial improvement over the uncorrelated random walk results shown in Figure 3.2. Also, the correlated random walk method employs parameters that have plausible physical interpretation. Although we did not attempt to do so, additional improvement of the FINS model fit could be achieved by further tuning the dispersive parameters and increasing the number of fish simulated.

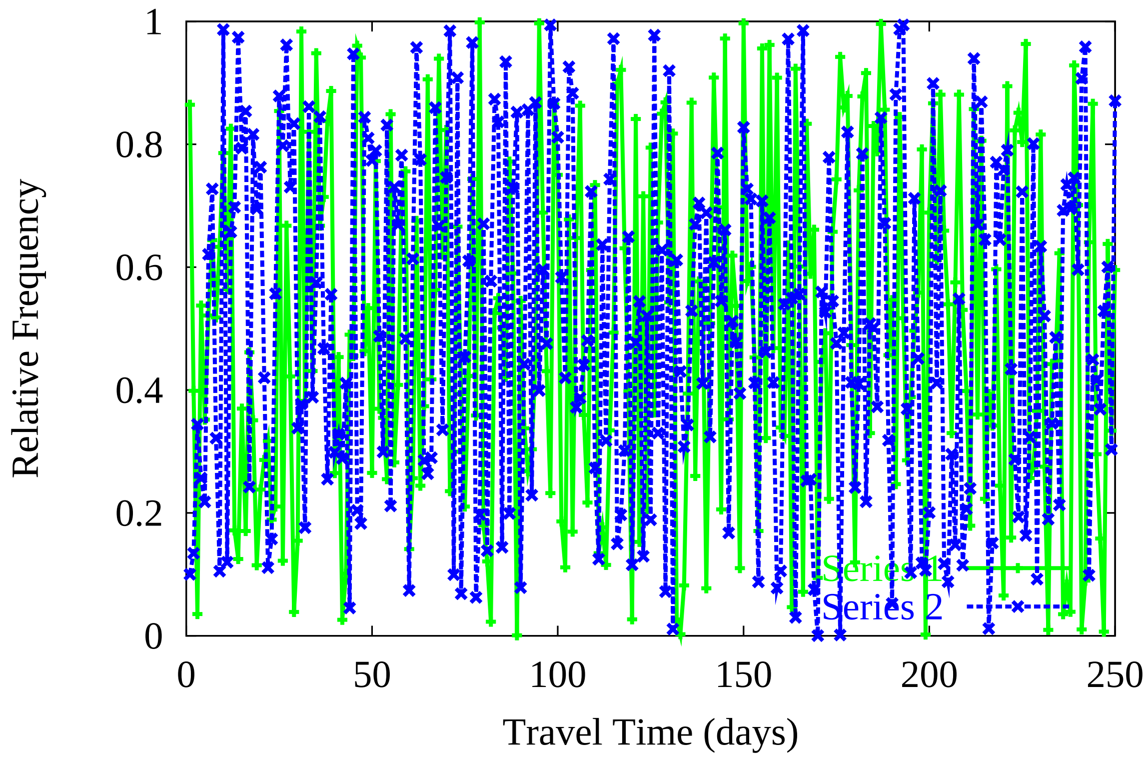

Figure 3.4: Sequences of uncorrelated random numbers

3.6 Conclusions

The analysis described here provides strong evidence that the correlated random-walk method is preferable to an uncorrelated random walk (or continuum advection-dispersion model) for simulating behavior and fate of individual fish.

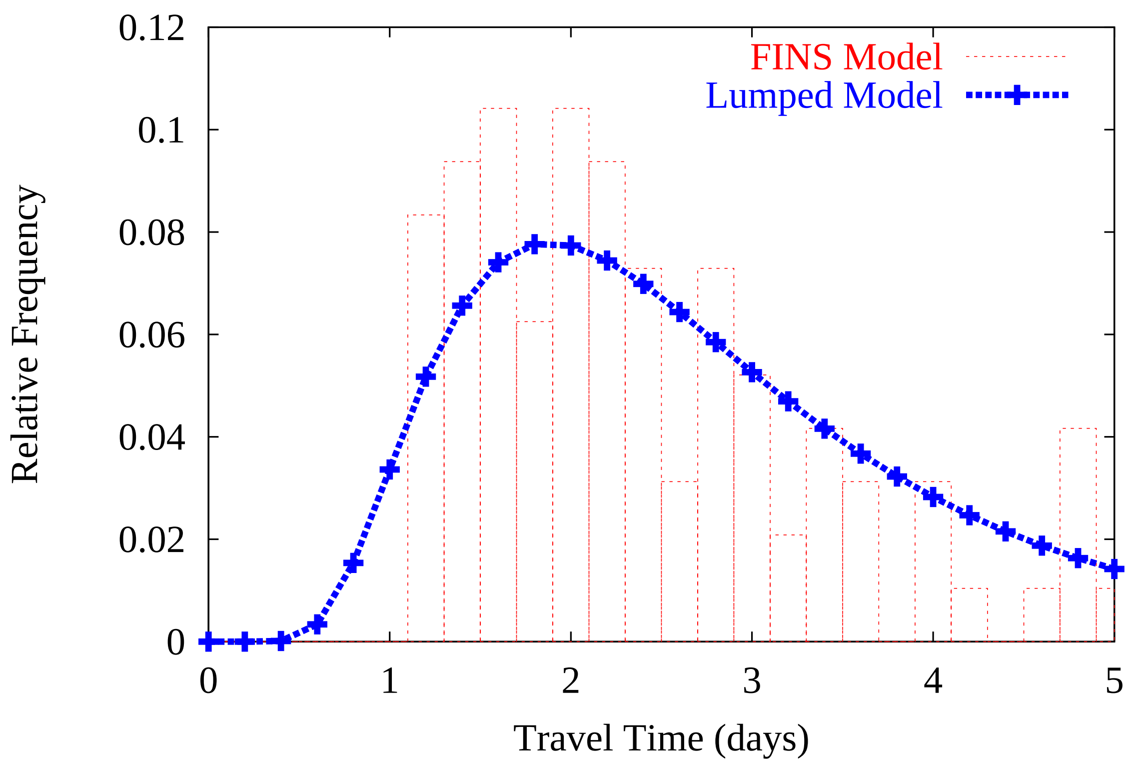

Figure 3.5: Comparison between the modeled arrival distribution from FINS (using the correlated random walk method) and the arrival distribution from the 1D lumped parameter model fitted to the PIT tag data.

4 Model Parameterization Based on Radiotelemetry Data

4.1 Introduction

The analysis of travel times derived from PIT tag observations, discussed in the previous chapter, provides motivation for use of a correlated random walk model of fish movements. However, the PIT data cannot provide detailed information needed to assess the form of such correlation, since individual fish are observed only at a limited number of points at major dams.

Fortunately, recent studies of individual fish movements using radiotelemetry methods have provided data that can be utilized for such an assessment. In this chapter, radiotelemetry observations collected by the U.S. Geological Survey (Biological Resources Division) are analyzed using FINS to provide further evidence for a correlated random walk model, and to assess the form and parameters of such correlation that can be used in FINS runs.

Radiotelemetry data collected in 1997 and 1998 in the McNary pool were provided to us by John Beeman of the U.S. Geological Survey, Biological Resources Division (Beeman et al. (1998)). In 1997, 64 fish were tracked through the McNary pool (a total of 1024 observations on approximately hourly intervals). In 1998, an additional 50 fish were tracked (total of 975 observations, again on hourly intervals). Most of the fish tracked were either Hatchery Steelhead (STHD) or Hatchery Spring Chinook (HSPC). Each fish was assigned a unique radio frequency, making it possible to track individuals. At each time of radio contact, the following information was recorded: Contact date and time, fish depth, depth of water column at fish location, water temperature, percent total dissolved gas saturation, and spatial coordinates (northing and easting in NAD27, Washington South datum). Contacts were made with each individual fish on hourly intervals to the degree possible. The radiotelemetry equipment is limited in its ability to detect fish swimming at depths greater than approximately 10 meters. Therefore, it is possible that some of the missing observations correspond to fish swimming at greater depths; however, the observed depth distributions (e.g., Figure 4.2) suggest that this is not a common occurrence. In addition to the hourly data, selected fish were monitored intensively (contacted on one- minute intervals) for several fifteen-minute periods. Information recorded in the intensive data are contact date and time, and fish depth. Water temperature and depth were recorded only at the start of each 15-minute sampling period. Fish locations (northing and easting) were not monitored on one-minute intervals.

4.2 Exploratory Data Analysis

4.2.1 Diurnal Effects

Mean fish depth was calculated as a function of time of day, and observed to be relatively constant (Figure 4.1).

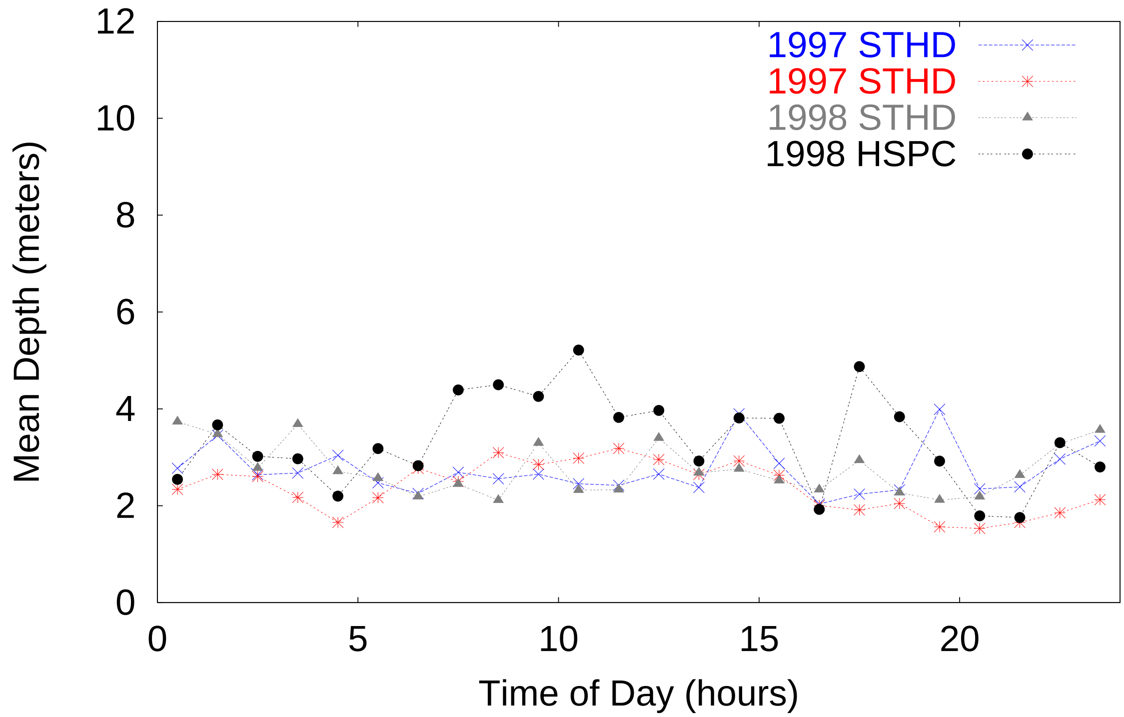

Figure 4.1: Mean depth by species and year as a function of hour of day (hour 0 is midnight).

4.2.2 Fish Depth Distribution

All observations of fish depth were grouped together for each species and year. The histograms of fish depth show that fish favored depths less than approximately 4 meters (Figure 4.2).

4.2.3 Fish Depth vs. Dissolved Gas Saturation

To see if fish demonstrated any tendency to swim at greater depths when encountering high levels of dissolved gas, scatter plots of fish depth versus dissolved gas saturation were generated for each species and year (Figure 4.3). However, no relationship between swimming depth and dissolved gas saturation levels is evident.

4.3 FINS-INV

The random-walk component of the FINS model applies random dispersive displacements (whether correlated or uncorrelated) to conceptually represent the portion of fish movements that cannot be explained by passive movement with the local water velocity (i.e., advection). Assessment of the statistical distribution of dispersive displacements from field observations requires that motions attributable to advection be removed from the observations. This can be accomplished using FINS in a quasi-inverse mode. We developed a modified version of FINS, called ”FINS-INV” to perform this analysis. FINS-INV places a simulated fish particle at the location and time of the first

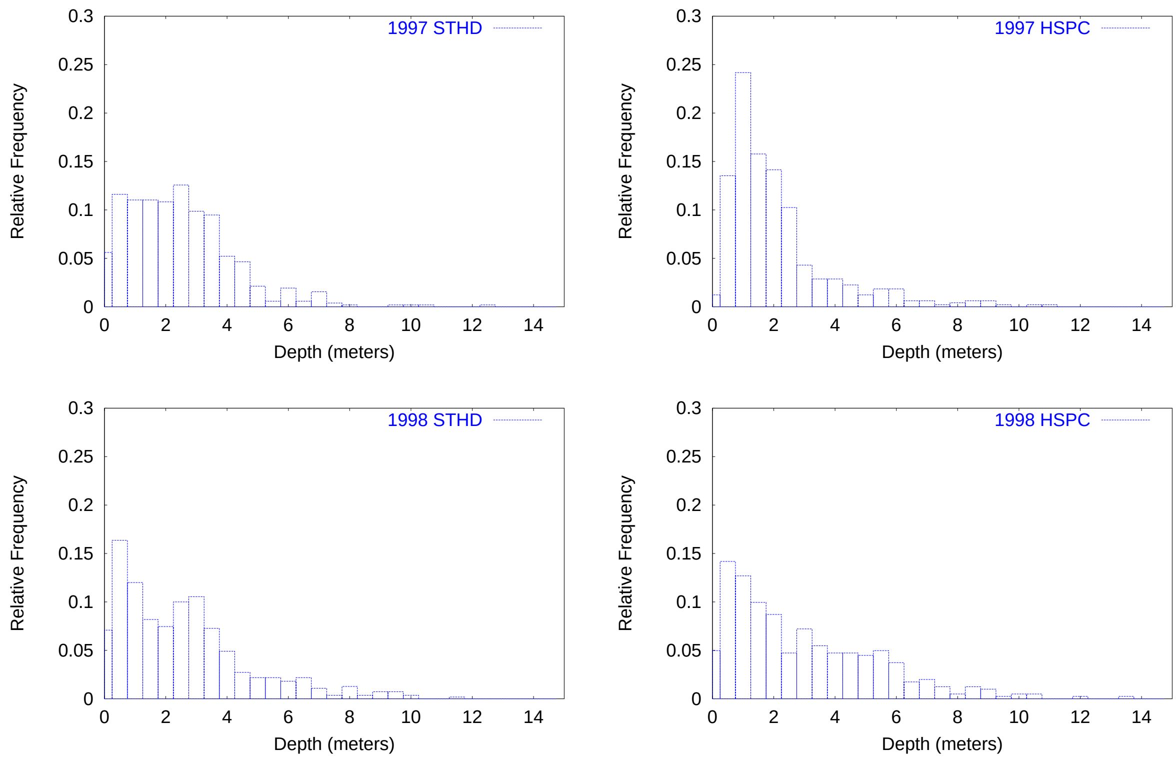

Figure 4.2: Histograms of fish depth. Depth observations greater than 10 m are unreliable and should be disregarded.

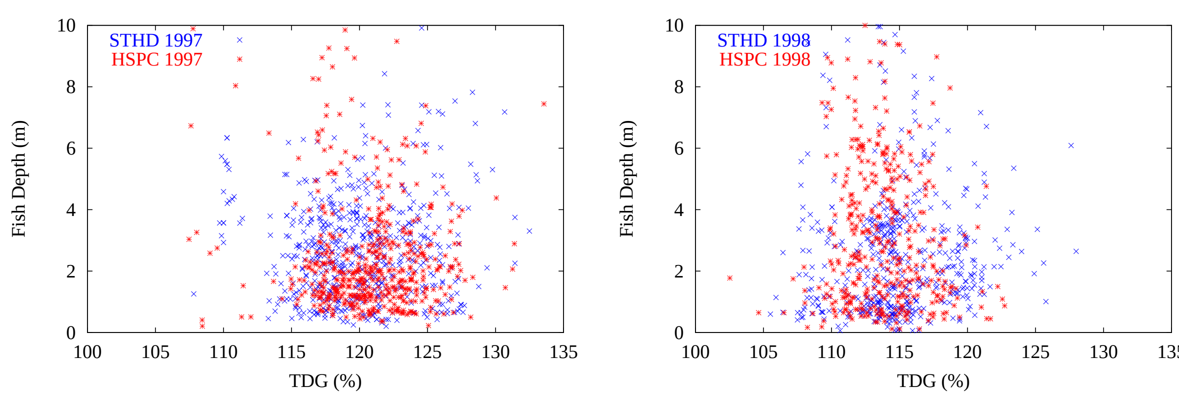

Figure 4.3: Scatterplots of fish depth versus dissolved gas saturation.

radiotelemetry observation of an actual fish. It then tracks the simulated fish forward in time, using advection only (with local velocities derived from the hydrodynamic simulation), until the time of the next radiotelemetry observation. The difference between the observed and simulated positions represents the sum of dispersive displacements that would need to be applied to the simulated fish in order to exactly match the behavior of the observed fish. These differences are converted to components along river mile (longitudinal) and perpendicular to the river thalweg (transverse), and written to an output file. The simulated fish is then moved to the observed fish's location, and the process repeated for the next radiotelemetry observation period. Repeating this exercise for a large number of fish and observations results in a distribution of dispersive displacements that can be analyzed in terms of temporal correlation and summary statistics. The results of such analysis provide both qualitative and quantitative information necessary to parameterize the FINS model.

4.4 Analysis of Dispersive Displacements

FINS-INV was executed for 56 fish tracked in 1997 and 50 fish tracked in 1998. Because map position was not recorded for the 1-minute interval intense sampling periods, only the hourly observations were employed in FINS-INV.

Figure 4.4 shows plots comparing the simulated (using advection only) and observed locations of three selected fish, generally representative of the range of obtained results. In the first case (Figure 4.4 top), the simulated and observed locations are generally quite similar, although it appears that the fish is moving slightly faster than the local water velocity. In the second case (Figure 4.4 center), simulated and observed locations are mostly similar, but a few large differences exist. In the third case (Figure 4.4 bottom), which occurs only a few times in the 1998 data, the observed fish did not out of the Snake River during the period of radiotelemetric monitoring, whereas the simulation predicted that it would have moved downstream. In most such cases, these fish eventually did migrate and were observed by fixed-receiving equipment at McNary Dam (John Beeman, personal communication). However, during the time period of this study the behavior of these few fish was anomalous with respect to that of the large majority of the tracked fish.

A complete set of plots for all fish analyzed using FINS-INV is available on the FINS website at http://etd.pnl.gov:2080/FINS/radtrack.htm. In general, the simulated and observed fish locations are similar, indicating that smolt migration in the McNary reach is dominated by passive movement with the local water velocity (advection).

Histograms of inferred displacements (difference between observed and simulated locations) for each species and year are shown in Figure 4.5. Note that, because of the inability to always contact each fish on an hourly basis in the field, there are some displacements that correspond to observation intervals greater than one hour. In the results presented below, displacements corresponding to an observation interval of $0.75hr < \Delta t < 1.25hr$ are used; all other calculated displacements have been discarded. The overall magnitude of displacements is similar between the two years. The maximum longitudinal displacements are on the order of 10000 feet (Figure 4.5 top two), or approximately 2.8 feet/second relative to local water velocity. Alternatively, the maximum transverse displacements are on the order of 3000 feet (Figure 4.5 bottom two), which is less than 1 foot/second relative to local water velocity. All distributions have a strong mode near zero, indicating that fish generally follow the local water velocity. However, the mode for steelhead is slightly greater than zero in both years, and that of the chinook is slightly less than zero (indicating

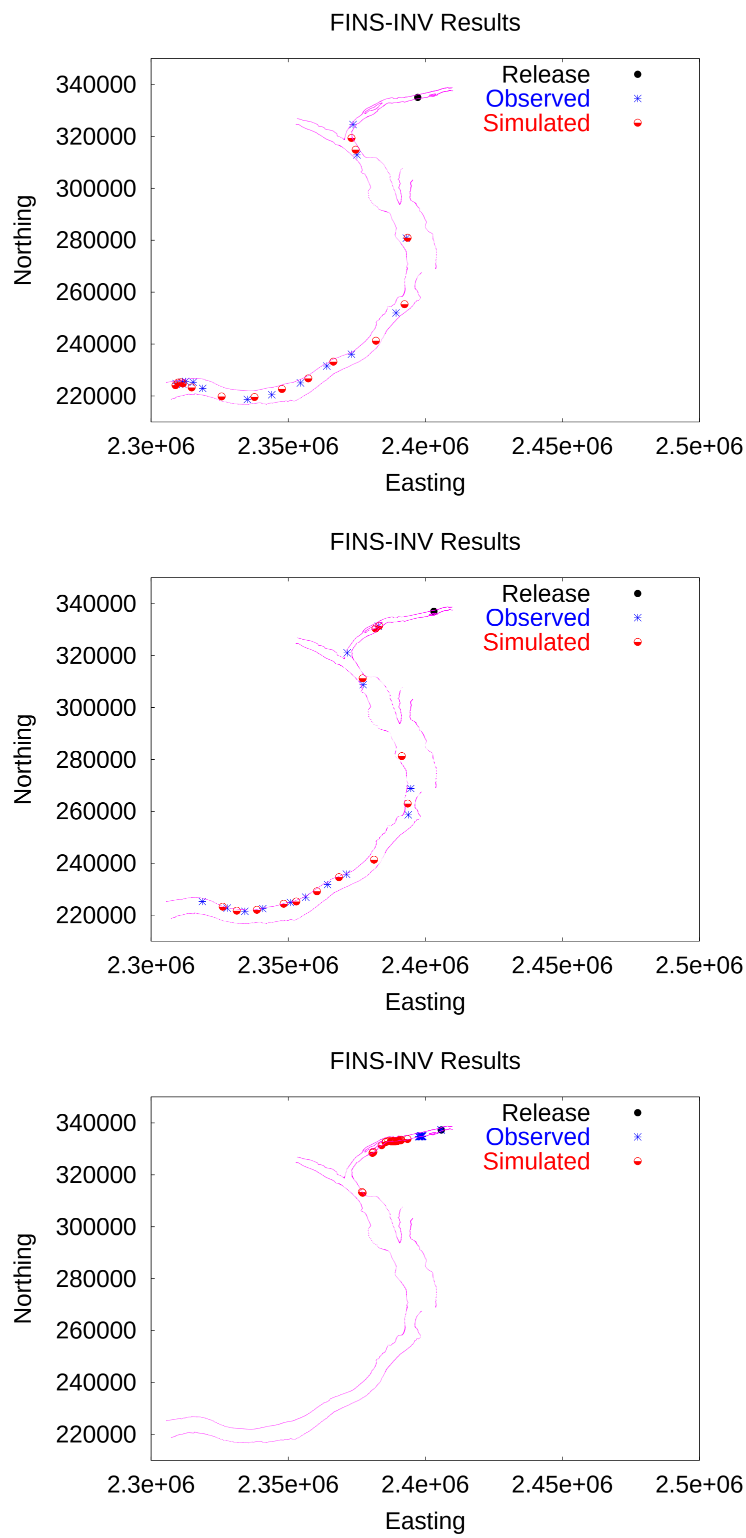

Figure 4.4: Plots comparing simulated (using advection only) and observed locations of three representative fish.

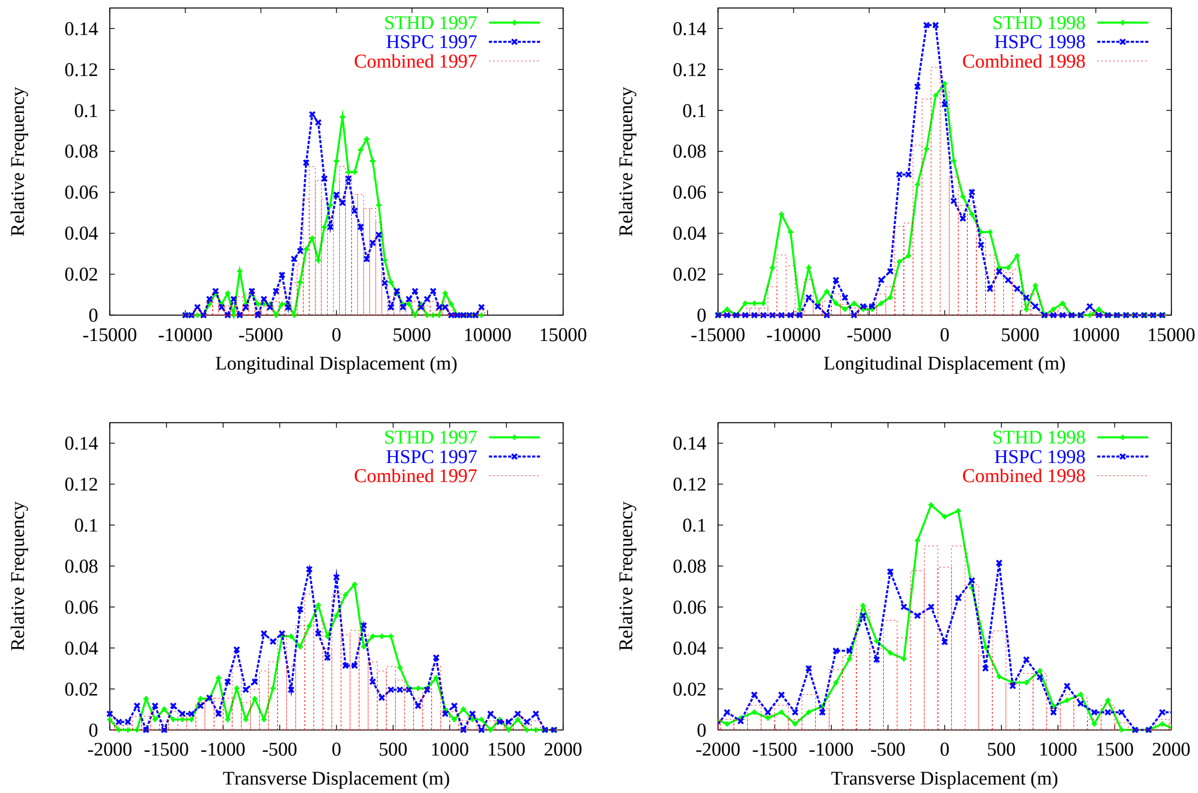

Figure 4.5: Histograms of inferred displacements for each species and year.

that steelhead generally swim faster than the chinook). Also, the steelhead appear to have a secondary mode at large negative longitudinal displacements (Figure 4.5 top right at approx. -10000 feet), possibly corresponding to the fish that did not leave the Snake River during the study period. This mode is particularly strong in 1998 (a lower-flow water year than 1997), but is anomalous as discussed above.

Figures 4.6 and 4.7 show temporal autocorrelations computed for each species (STHD, HSPC, and combined), year (1997, 1998), and displacement component (longitudinal and transverse). Both longitudinal and transverse correlations appear to be much stronger in 1997 than in 1998. Also, correlations in longitudinal displacements are larger than those in transverse displacements. There is a puzzling difference in the longitudinal correlation pattern between 1997 and 1998. In 1997, both steelhead and chinook show a strong correlation, persisting over several hours. However, in 1998 chinook exhibit little if any correlation but steelhead are strongly correlated (and increasing with increasing time lag). We found that, removal of three anomalous fish (of 29 total fish) from the steelhead dataset reduced the apparent correlation to a level consistent with that of the chinook (Figure 4.8).

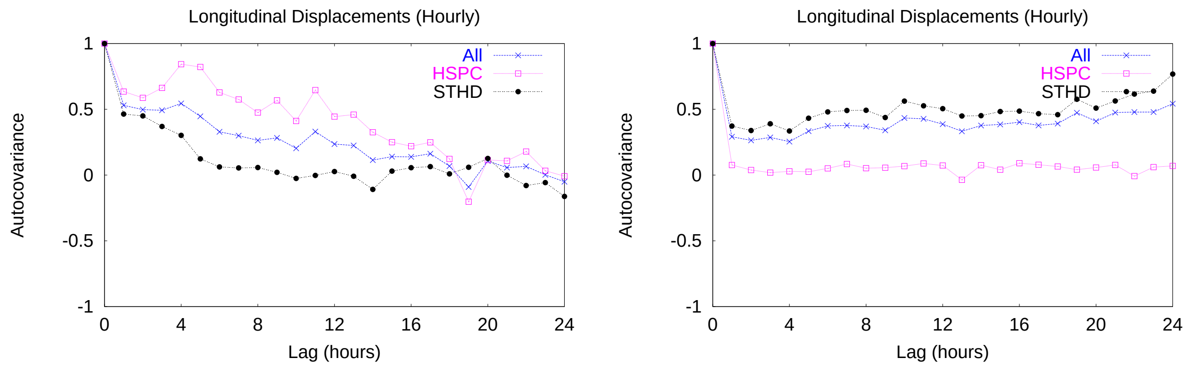

Figure 4.6: Temporal autocorrelations of longitudinal displacement for each species in 1997 (left) and 1998 (right).

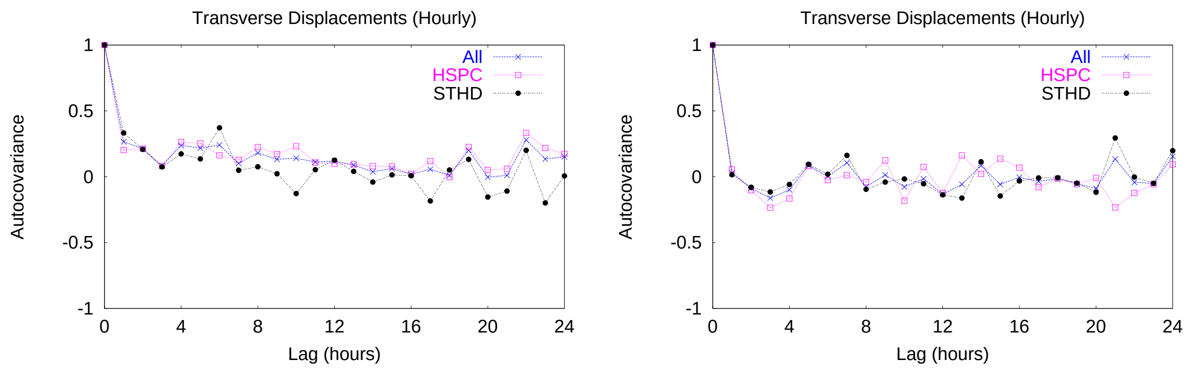

Figure 4.7: Temporal autocorrelations of transverse displacement for each species in 1997 (left) and 1998 (right).

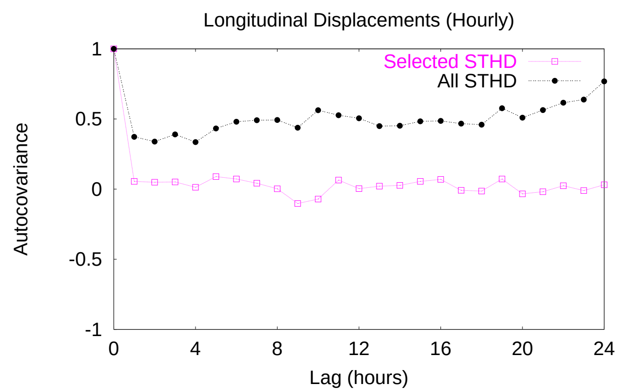

Figure 4.8: Temporal autocorrelations of longitudinal displacement for all 1998 steelhead and 1998 steelhead with the three anomalous fish fish removed.

4.5 FINS Parameter Estimation

Most of the radiotelemetry observations are on approximately one-hour intervals. However, earlier test runs indicate that a maximum time step of 50 seconds is required for FINS to minimize numerical error. To use the inferred hourly dispersive displacements described above to derive parameters that can be used in FINS, we must determine the appropriate magnitude of displacements and degree of correlation at a 50- second time scale that gives rise to the observed displacements and autocorrelations at hourly time scales.

Monte-Carlo simulation techniques, using pseudo-random number generation routines, were used to simulate sequences of random displacements at 50-second intervals. These simulated sequences were then summed onto one-hour intervals and compared statistically to the observed displacements. Parameters of the 50-sec simulation sequences were adjusted in trial-and-error fashion until an appropriate match between simulated and observed displacements on the one-hour time scale was achieved.

In FINS, the longitudinal displacement is calculated using the following equation (modifications to account for the grid transformation not shown):

$$dlong = (r_u - 0.5)(\sqrt{24\Delta t \alpha_l v} + \sqrt{24\Delta t d_x}) \tag{4.1}$$

where r_u is a uniform random number on [0,1], v is the magnitude of local flow velocity, Δt is the time step, α_l is the longitudinal dispersivity (units of length), and d_x is the local diffusion coefficient. Assuming the displacements to be independent of local velocity allows us to focus on the selection of d_x. It is then possible to later re-allocate the dispersive effect between d_x and α_l by assuming some average local velocity. Incorporating these assumptions, and setting Δt = 50s, reduces the above relation to:

$$dlong = (r_u - 0.5)34.6\sqrt{(}d_x) \tag{4.2}$$

The random number sequence r_u can be generated in any number of ways. Specifically, we consider either uncorrelated (independent) or autocorrelated sequences as discussed in Chapter 2. For uncorrelated sequences, the GENUNF function from the RANLIB library (downloaded from http://www.netlib.org) was used as the fundamental random number generator. Sequences of 10000 50-second displacements were generated using the specified degree of dispersion (dx parameter), then displacements on one-hour intervals were determined and summarized statistically.

Initial tests of correlated random number sequences generated using the method described in Chapter 2 resulted in uniformly-distributed displacements that did not match the observed histogram shapes (Figure 3.5). Therefore, a different method of generating correlated random number sequences was employed, specifically ”sequential gaussian simulation” as implemented in the GSLIB geostatistical software library (http://www.gslib.com). This method results in a gaussian or normal distribution of random numbers, similar in shape to the observed dispersive displacements in Figure 3.5. However, this method is more complex, and the simulation of random number sequences is therefore performed externally to FINS and the resulting sequences are read in from input files.

A spherical correlation model was employed, and parameterized by the correlation range (time at which correlation effectively becomes zero). For sequences with a high degree of correlation, nested simulations were performed to preserve correlation at long, intermediate, and short distances. Sequences of 72000 50-second displacements were generated, then displacements on one-hour intervals were determined and summarized statistically. For both methods, the results were compared to the statistical summaries of observed displacements to evaluate the goodness of the model and parameterization. The 50- second time scale model parameters were then adjusted in subsequent runs until a good match was obtained.

Since the observed behavior varies by year and species, several different cases are considered here:

4.5.1 Case 1: 1998 HSPC Longitudinal Displacements

1A: Uncorrelated displacements:

Since no correlation is apparent at the 1-hour time scale in this case, it is possible to use the purely random displacement model. The only parameter that can be varied to match the observations is the longitudinal dispersion parameter (D_L). Figure 4.9 is a chart showing the simulated variance of hourly displacements as a function of D_L; note that the variance of the "observed" displacements is 6.43E+06 (ft^2) in this case. The relationship is strongly linear (as would be expected from

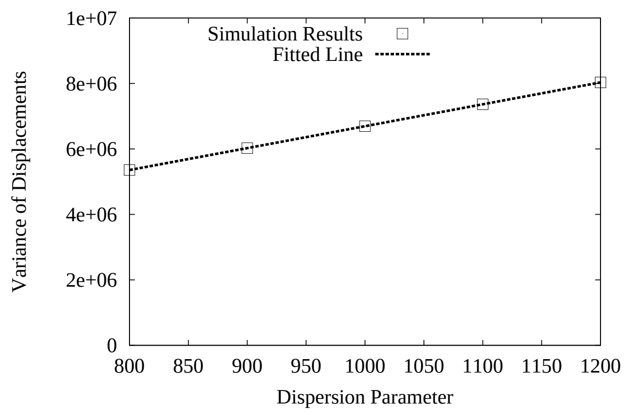

Figure 4.9: Simulated variance of hourly displacements as a function of D_L.

the underlying Fickian dispersion model), and the fitted line gives a best-fit estimated dispersion parameter (to match the observed variance) of $D_L = 960.1(ft^2/s)$. Using$D_L = 960.1 ft^2/s$, the simulated and observed histograms of displacements correspond very well (Figure 4.10). Also, the covariance plots demonstrate that the simulated displacements exhibit zero correlation at either the local (50-second) or hourly time scales (Figure 4.11).

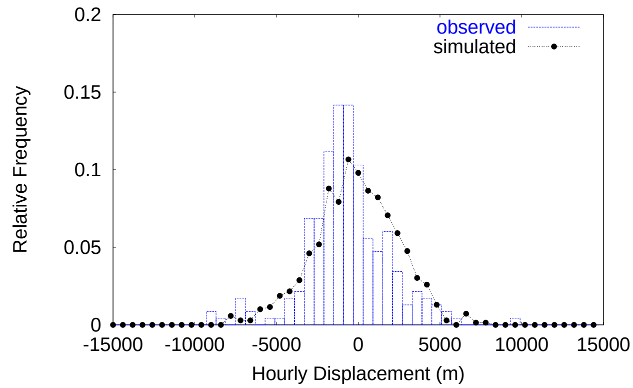

Figure 4.10: Comparisons of the simulated and observed histograms of displacements.

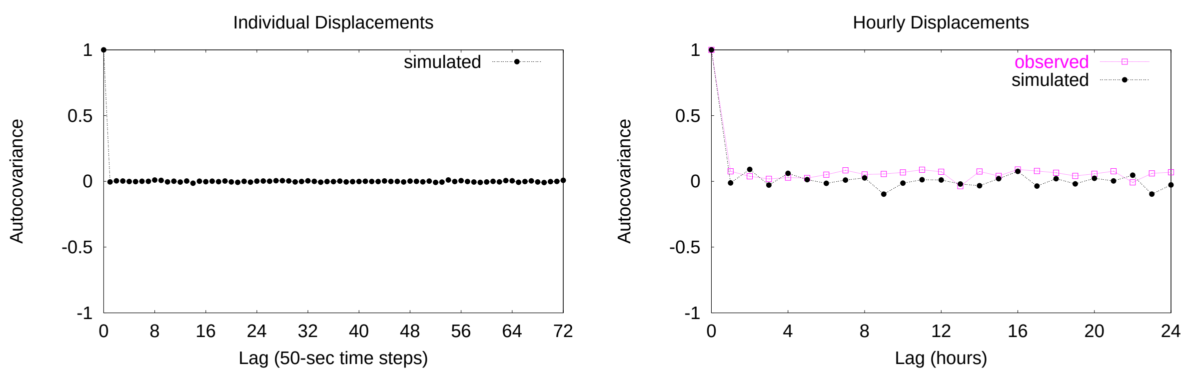

Figure 4.11: Covariance plots of simulated displacements at local and hourly time scales.

1B: Correlated Displacements

A relatively small degree of correlation can be imposed at the local (50-second) time scale without introducing significant correlation at the hourly time scale. This will allow reduction of the required maximum swim velocity while still honoring the observations. Figure 4.12 is a graph of the value of D_L required to match the observed variance of hourly displacements versus the correlation range:

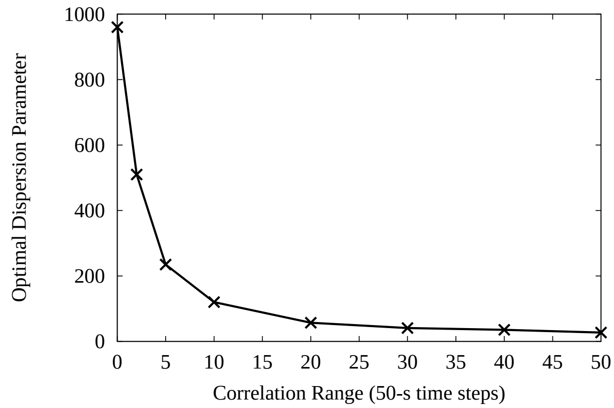

Figure 4.12: Correlation range versus the value of D_L required to match the observed variance of hourly displacements.

Note that Figure 4.12 also shows the optimal solution for case 1A (no correlation). Any point on the curve provides an equally good match to the observations, except that values of correlation range greater than about 30 time steps lead to slightly excessive correlation at the hourly time scale. As the correlation range is increased, the maximum local velocity required to achieve the observed distribution of hourly displacements decreases. At a correlation range of 30 time steps (correlation over approximately 25 minutes), the maximum required local velocity (as represented by 3 times the standard deviation) is approximately 3.8 feet/second, greatly reduced from the 10.7 feet/second required for the uncorrelated case and possibly more biologically realistic.

The observed and simulated histograms (Figure 4.13), and the local and hourly correlations (Figure 4.14) summarize the results for the case of range = 30 time steps and D_L = 41 ft^2/sec, and demonstrate the match between model results and observations.

4.5.2 Case 2: HSPC 1997 Longitudinal Displacements

Since strong correlation in displacements is exhibited in this case even at the hourly time scale (see Figure 4.6 left) , the purely random local displacement model is clearly inappropriate and will not be considered. Because there is observable correlation at the hourly time scale in this case, the model parameterization is more constrained than in case 1B. That is, rather than having a number of combinations of correlation ranges and dispersion parameters that lead to a reasonable fit, we can expect to find a single optimal pair. By trial-and-error, the values of these two parameters found to provide a good fit to the observations are: $D_L = 17(ft^2/sec)$ and $corr.range = 1500(timesteps)$, where a time step is 50 seconds. Graphs showing the match between simulated and observed

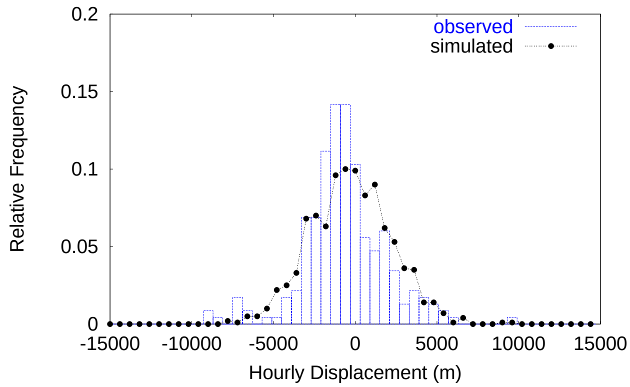

Figure 4.13: Observed and simulated histograms for the case of range = 30 time steps and D_L = 41 ft^2/sec.

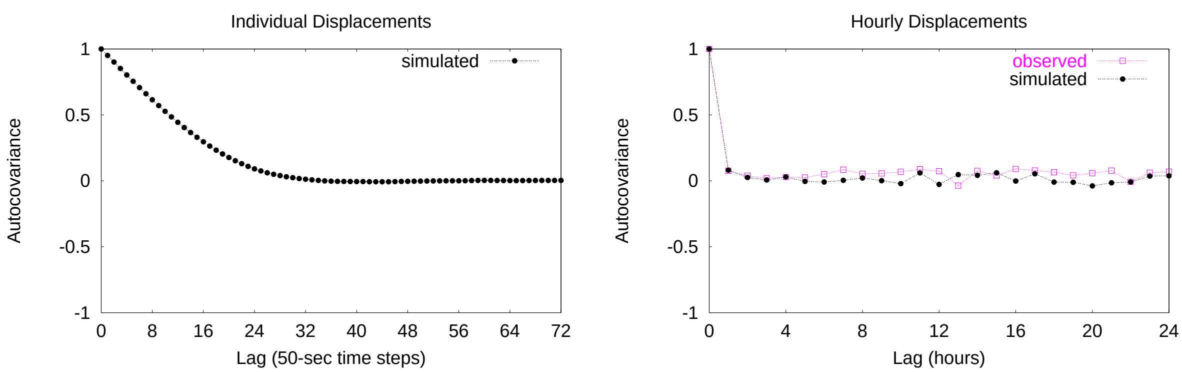

Figure 4.14: Plots of local and hourly correlations for the case of range = 30 time steps and D_L = 41 ft^2/sec.

properties of the distribution of hourly displacements are shown in Figures 4.15 and 4.16 for the case of range = 1500 time steps and D_L = 17 ft^2/sec.

4.5.3 Case 3: STHD 1997 Longitudinal Displacements

The pattern of displacements for 1997 steelhead (STHD) is generally similar to that of 1997 chinook (HSPC) with the following two differences: 1) the correlations are generally smaller, though still significant, and 2) the histogram peak is shifted indicating generally faster travel velocities. As was done for the 1997 chinook, the correlated random walk model is employed here, but with a lower degree of correlation. Parameters selected using trial-and-error approach are: $D_L = 20(ft^2/sec)$ and $corr.range = 450(timesteps)$. Graphs showing the match between simulated and observed properties of the distribution of hourly displacements are shown in Figures 4.17 and 4.18 for the case of range = 450 time steps and D_L = 20 ft^2/sec. Note that, because of the non-normality of the observed histogram (a secondary mode and non-zero primary mode in Figure 4.17), it is not possible to match both the shape and variance using a unimodal distribution.

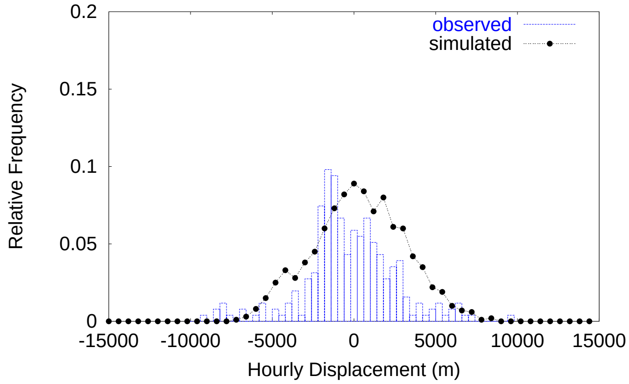

Figure 4.15: Observed and simulated histograms for the case of range = 1500 time steps and D_L = 17 ft^2/sec.

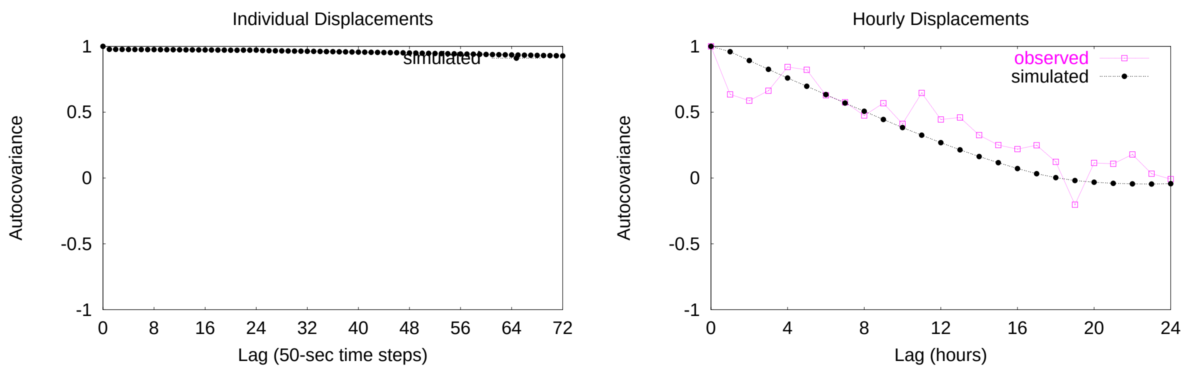

Figure 4.16: Plots of local and hourly correlations for the case of range = 1500 time steps and D_L = 17 ft^2/sec.

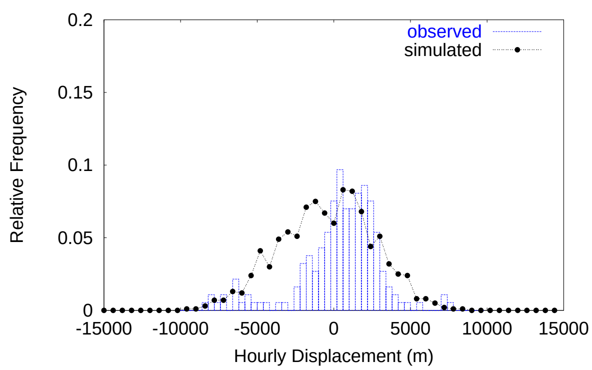

Figure 4.17: Observed and simulated histograms for the case of range = 450 time steps and D_L = 20 ft^2/sec.

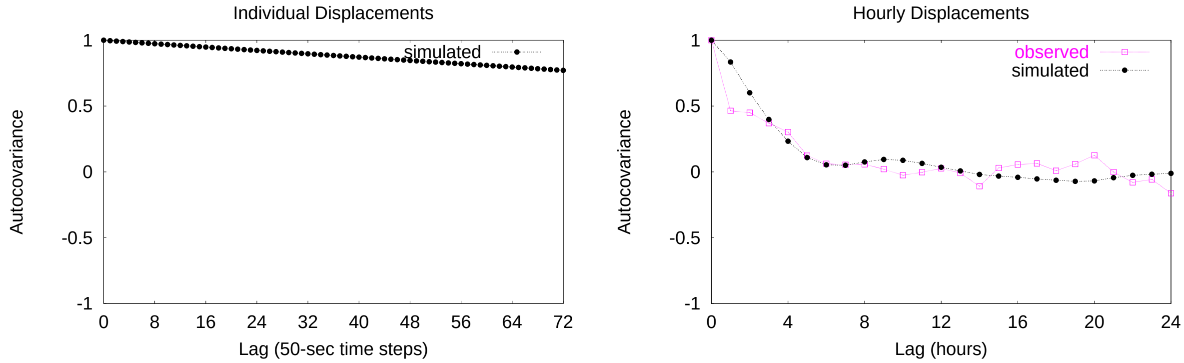

Figure 4.18: Plots of local and hourly correlations for the case of range = 450 time steps and D_L = 20 ft^2/sec.

The parameters used lead to a variance of 9.6E+06 ft^2, which is low compared to the observed value of 2.54E+07, yet the simulated distribution is significantly wider than the primary mode of the observed distribution. Therefore this parameterization represents a compromise between representing the sharpness of the primary peak of the observed histogram and representing the degree of spread (variance) of the distribution.

4.5.4 Case 4: Combined 1997 Transverse Displacements

The distributions of transverse displacements do not vary strongly by species, so for this case we consider both HSPC and STHD combined. The hourly correlation has similar shape to the 1997 longitudinal displacements for STHD, but with slightly weaker correlation. The range of displacements is smaller than the longitudinal case by approximately a factor of 5. This indicates that both the correlation range and the dispersion parameter should be smaller for this case than for the previous case. Parameters selected using trial-and-error approach are: $D_T = 1.5(ft^2/sec)$ and $corr.range = 150(50 - sectimesteps)$. Graphs showing the match between simulated and observed properties of the distribution of hourly displacements are shown in Figures 4.19 and 4.20 for the case of range = 150 time steps and D_T = 1.5 ft^2/sec.

4.5.5 Case 5: Combined 1998 Transverse Displacements

The hourly transverse displacements in 1998 do not exhibit any correlation at the hourly time scale. Therefore, and because the magnitude of transverse displacements are small relative to the longitudinal displacements, the uncorrelated model may be appropriate. Using the trial-and-error approach, an optimal value of the dispersion parameter $D_T = 85.9(ft^2/sec)$ was selected. This corresponds to a maximum transverse velocity of 3.2 ft/sec. However, correlation of up to 30 time steps might also be reasonable based on experience (see case 1 above), and would reduce the maximum required velocity. Using a correlation range of 30 time steps, the required dispersion parameter is reduced to $D_T = 4.1(ft^2/sec)$, and the maximum transverse velocity is reduced to 1.5 ft/sec. Graphs showing the match between simulated and observed properties of the distribution of hourly displacements (for the correlated case) are shown in Figures 4.21 and 4.22.

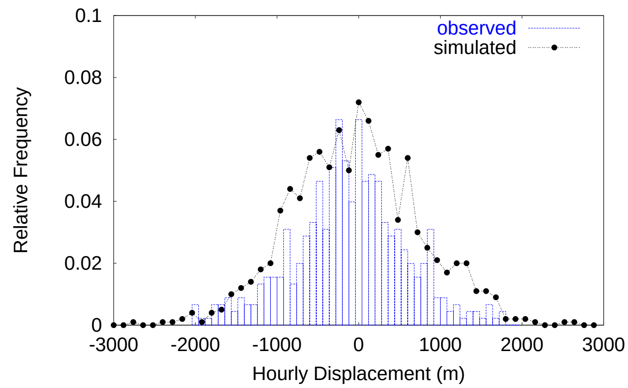

Figure 4.19: Observed and simulated histograms for the case of range = 150 time steps and D_T = 1.5 ft^2/sec.

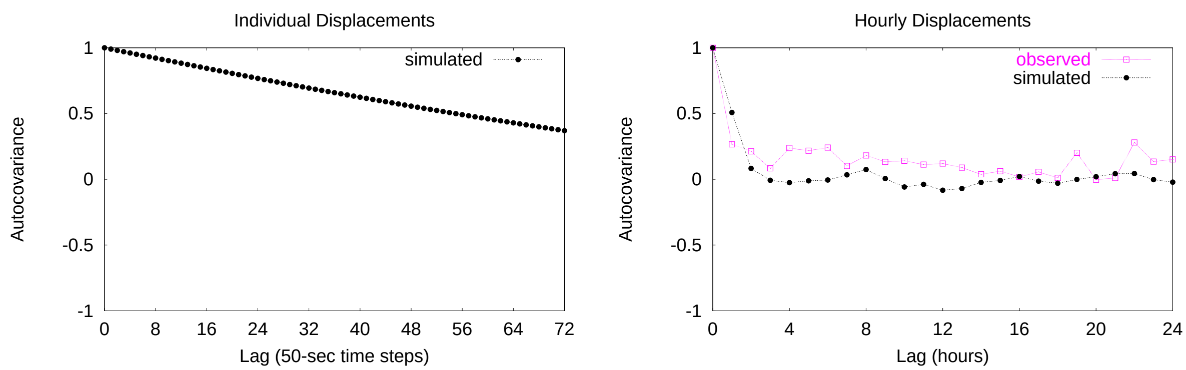

Figure 4.20: Plots of local and hourly correlations for the case of range = 150 time steps and D_T = 1.5 ft^2/sec.

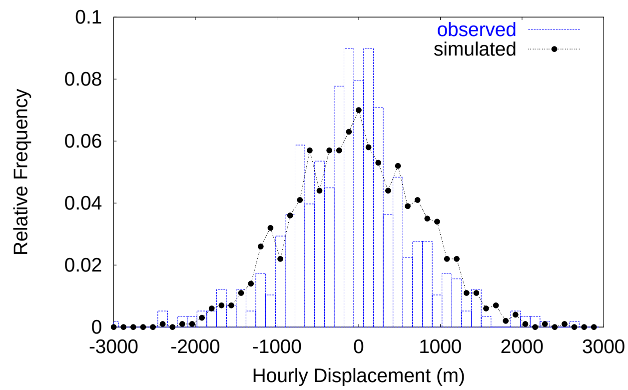

Figure 4.21: Observed and simulated histograms for the case of range = 30 time steps and D_T = 4.1 ft^2/sec.

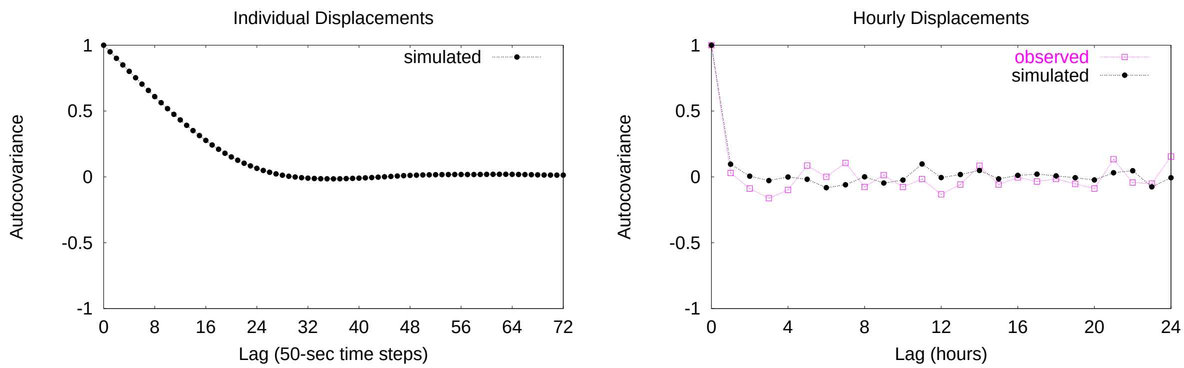

Figure 4.22: Plots of local and hourly correlations for the case of range = 30 time steps and D_T = 4.1 ft^2/sec.

4.5.6 Summary

Observations of individual fish movements on an hourly time scale, developed using radio tracking techniques, were used to evaluate and parameterize the FINS model. In general, both hatchery chinook and steelhead movements in the McNary reach of the Columbia/Snake rivers are dominated by advection (movement with the local water velocity). Deviations from purely advective motion derived by comparing model results with observations provide a means of estimating dispersion models and parameters for FINS. Several different cases (water years, species, and component of dispersion) were considered here and model parameterizations were developed for each. These results are summarized in table 3.1.

Year	Species	Dispersion Component	Correlation Range (50-sec time steps)	Dispersion (ft^2/sec)
1997	STHD	Longitudinal	450	20
1997	STHD	Transverse	150	1.5
1997	HSPC	Longitudinal	1500	17
1997	HSPC	Transverse	150	1.5
1998	STHD	Longitudinal	30	41
1998	STHD	Transverse	30	4.1
1998	HSPC	Longitudinal	30	41
1998	HSPC	Transverse	30	4.1

Table 4.1: Summary of longitudinal and transverse displacement parameters determined for each species and year.

The transverse component of dispersion is one order of magnitude smaller than the longitudinal component. There is significant variability between years, and between species in 1997, but both species behaved similarly in 1998. The peaks of the observed histograms of displacements were slightly non-zero, with steelhead generally moving faster and chinook slower than the local water velocity. However, this shift was modest and was not accounted for in the model runs performed here, although this aspect of the behavior could easily be incorporated into FINS if deemed significant. In all cases analyzed, a correlated random walk provided better model results, although in cases where correlation was not observable at the hourly time scale it would also be possible to use the uncorrelated model.

In general, these results indicate that the FINS model is capable of simulating realistic smolt migration paths within the McNary reach, and defensible parameterizations for two different species and years have been obtained.

4.5.7 Analysis of Depth Changes

The radiotelemetry observations also provide information on the temporal sequence of swimming depth of individual fish. In this case, the intensive (1-minute interval) data are the most useful, since they correspond closely to the 50-second time step used for FINS simulations.

In FINS, the depth at which a fish swims is simulated independently of its lateral (map view) position. Since the velocity fields provided from MASS2 are two-dimensional, vertical smolt movements cannot be driven by water velocity (advection). We therefore wish to determine an appropriate random-walk model, based on radiotelemetry observations, that can be used to simulate depth of individual smolts.

Linear Depth Preference Model:

One approach, implemented in FINS v1.06, is the generation of vertical position based only on the vertical position (depth) at the previous time step. A preferred depth is specified, with either a linear or exponential model specifying the velocity toward the preferred depth as a function of distance from the preferred depth. This can be combined with a random model of specified variance to obtain an overall depth variation model.

To test the validity of this approach, we computed changes in depth over the 1-minute intervals for the 1997 HSPC and grouped them according to the depth at the beginning of the time interval. If this model is appropriate, one would expect to see a mean upward velocity when below the preferred depth, and a mean downward velocity when above the preferred depth, with the velocity magnitude increasing with distance away from the preferred depth. As evident in Figure 4.23, these data support the type of model described above, with a fairly linear relationship between the magnitude of depth change and the distance from the mean or preferred depth (2.3m). Figure 4.24 shows the magnitude of vertical velocity as a function of initial distance from the mean depth, for the five depth intervals in which 30 or more observations were available. A line fitted to the four observations near or below the mean depth has a strong linear correlation; the single point for which the starting point was above the mean depth has a higher velocity magnitude, indicating that fish very near the water surface have a strong tendency to move rapidly toward the preferred depth.

The overall standard deviation of depth changes was 1.23 meters, and did not vary much with the initial depth. Therefore, a linear depth preference model combined with a random variation model may be appropriate.

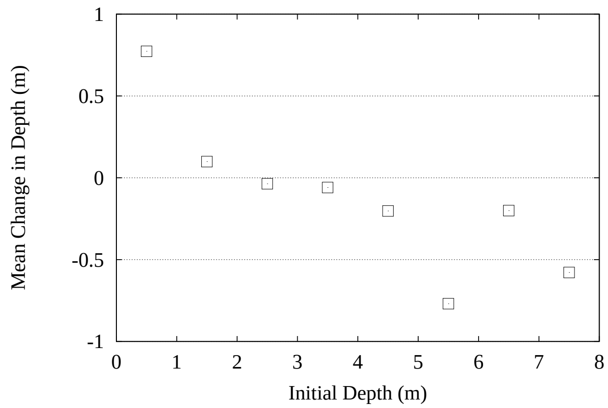

Figure 4.23: Mean change in depth (over a 1-minute interval) as a function of starting depth for 1997 HSPC (Note that the mean overall depth at which fish were observed was 2.3 meters)

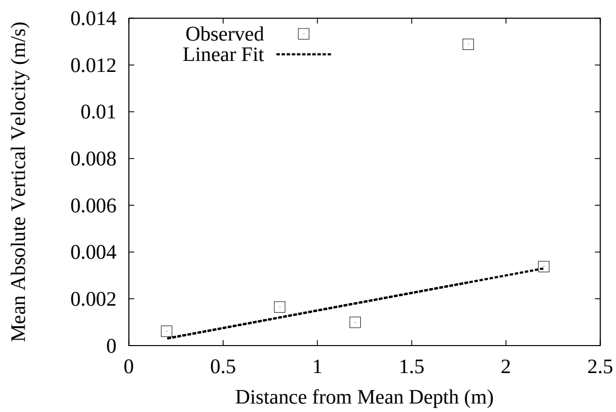

Figure 4.24: Magnitude of vertical velocity as a function of initial distance from the mean depth for 1997 HSPC

As shown in the Figures 4.25 and 4.26, the results for 1997 STHD are very similar, except that the mean depth is slightly greater (3.01 m).

Similar results were obtained for 1998 radio tracking observations, for both HSPC and STHD, suggesting that the linear depth preference plus random fluctuations model will work well for a wide variety of conditions. Table 3.2 summarizes model parameters for each species and year considered.

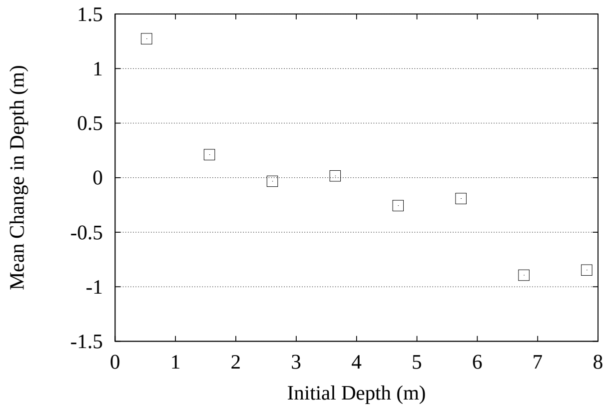

Figure 4.25: Mean change in depth (over a 1-minute interval) as a function of starting depth for 1997 STHD (Note that the mean overall depth at which fish were observed was 3.01 meters)

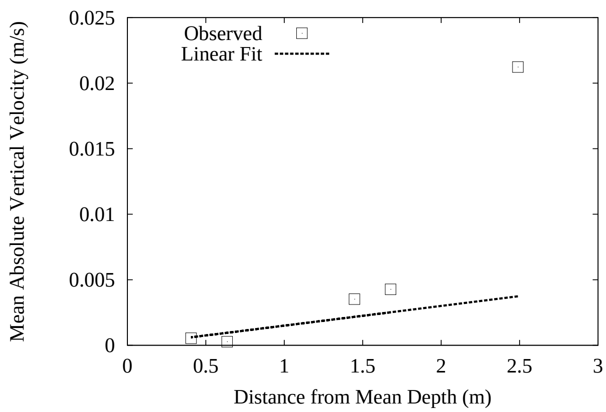

Figure 4.26: Magnitude of vertical velocity as a function of initial distance from the mean depth for 1997 STHD

Year	Species	Preferred Depth (m)	Velocity Coefficient (1/sec)	Standard Deviation of Velocity (m/s)
1997	HSPC	2.32	0.0015	0.021
1997	STHD	3.01	0.0023	0.023
1998	HSPC	3.06	0.0019	0.037
1998	STHD	2.74	0.0041	0.037

Table 4.2: Linear Depth Preference Model parameters for each species and year.

5 Example Runs and Output

5.1 Description of Time Periods (1997 and 1998)

1997 and 1998 were both above-normal water years, but 1997 was an extremely high flow year. In 1997, the mean daily average flow rate of the Columbia River at McNary dam was 259 kcfs (thousands of cubic feet per second) and the maximum single-day average flow was 578 kcfs. In 1998, the mean daily average was 173 kcfs (67flow was 414 kcfs. Figure 5.1 the observed flow rates at McNary Dam in 1997 and 1998.

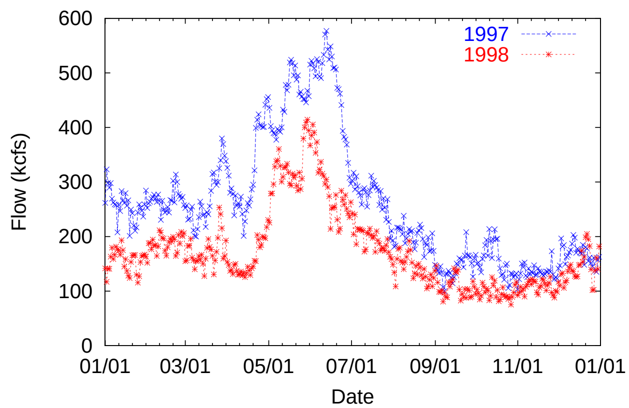

Figure 5.1: Observed flow rates at Mcnary Dam for 1997 and 1998

5.1.1 MASS2 Modeling Results

The Modular Aquatic Simulation System 2D (MASS2) is a two-dimensional, depth-averaged hydrodynamics and transport model (for detailed model description see Part 1 of report series Richmond, Perkins, Scheibe, 1998). MASS2 was used to simulate the time-varying (unsteady) distributions of depth-averaged velocity, depth, dissolved gas level, and temperature in the reach extending from the Ice Harbor Dam tailwater, through the Clover Island area and ultimately to the head of the McNary Dam forebay. The bathymetric grid for this region was generated from multiple sources of bathymetric data using Gridgen 9.1 (Part 6 of report series Richmond, Perkins, Scheibe, 1998). We then used McNary Dam forebay elevation as the downstream boundary condition and calibrated the model to reproduce tailwater elevations at Ice Harbor Dam (Part 6 of report series Richmond, Perkins, Scheibe, 1998). We also qualitatively verified the correspondence between simulated velocities and those measured with an Acoustic Doppler Current Profiler (ADCP) in numerous location throughout the reach.

For the FINS modeling runs, MASS2 was run for the time periods overlapping with radiotelemetry data to produce 2-dimensional distributions of depth-averaged velocity, depth, dissolved gas, and temperature at 0.5 hr intervals. The FINS model simulates the downstream transport of migrating smolts along streamlines in the velocity distributions. Note that fish drifting along the left half of the river are susceptible to entrapment in Burbank Slough (Figure 5.2) or the the low-velocity regions near Badger Island (Figures 5.3 and 5.4), where the dissolved gas levels and temperatures are higher (Figures 5.5 and 5.6). Also note in Figure 5.6 the distance required below the confluence of the Snake and Columbia Rivers for dissolved gas mixing to occur.

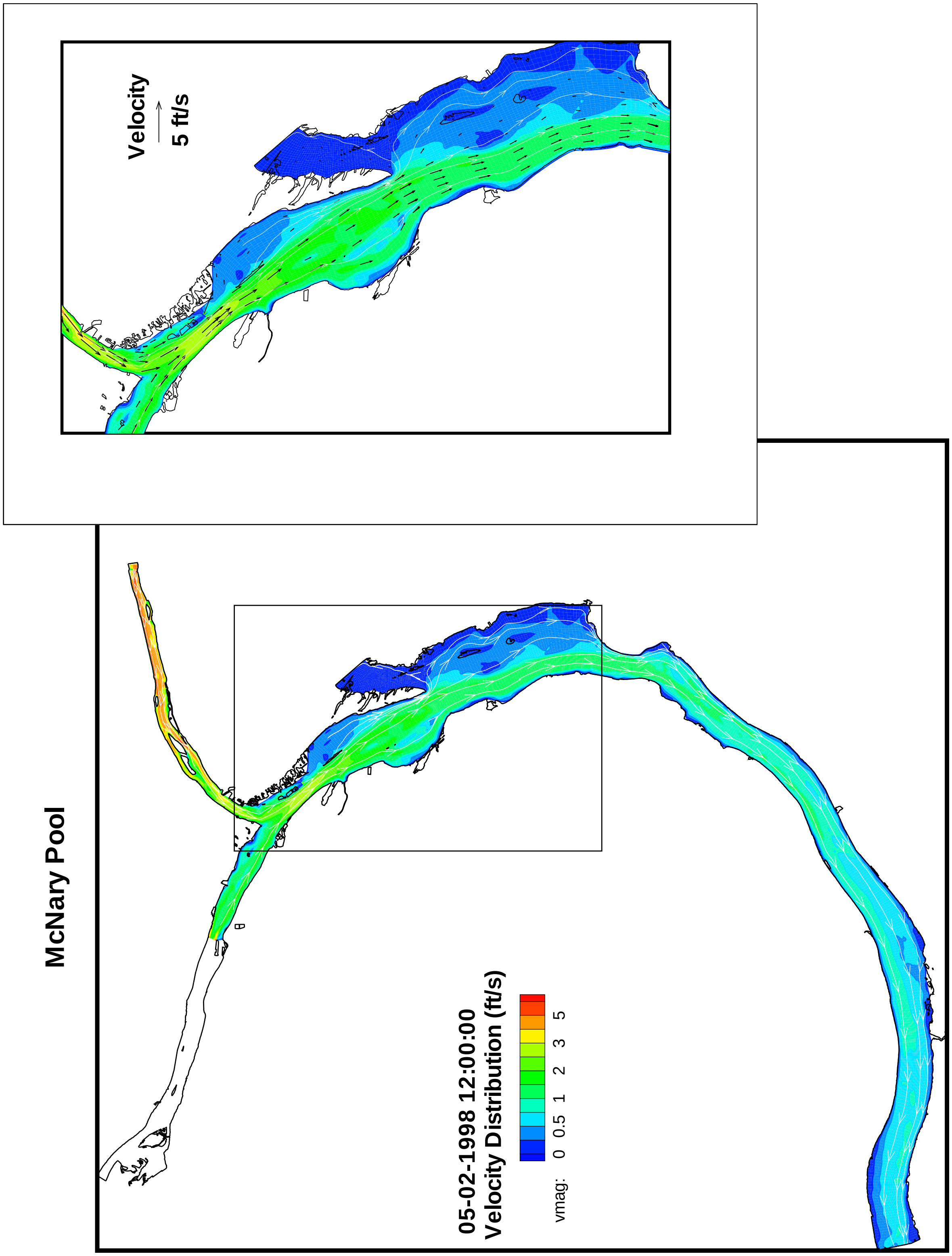

Figure 5.2: Velocity distribution gererated by MASS2 showing streamlines and velocity vectors (inset).

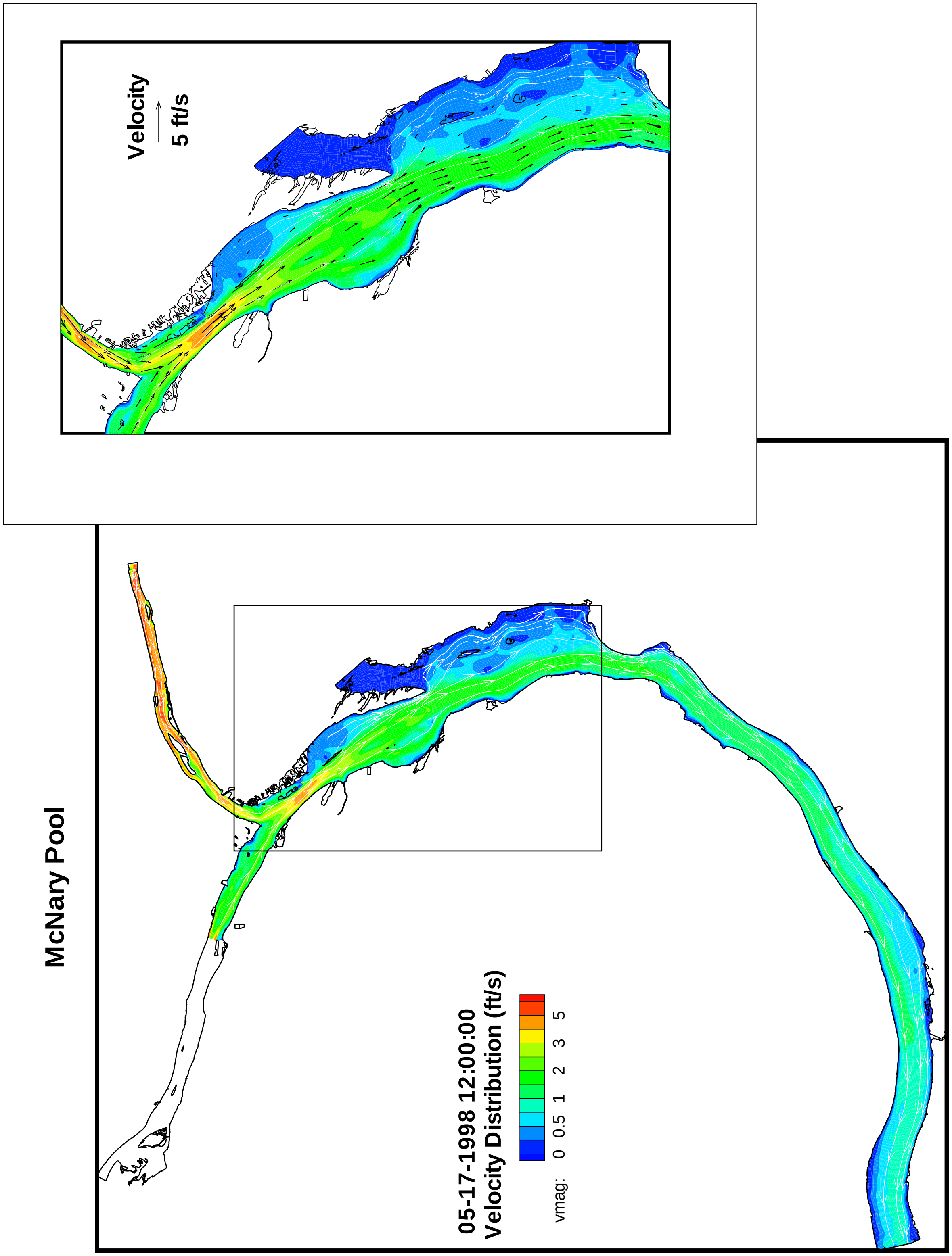

Figure 5.3: Velocity distribution generated by MASS2 showing streamlines and velocity vectors (inset).

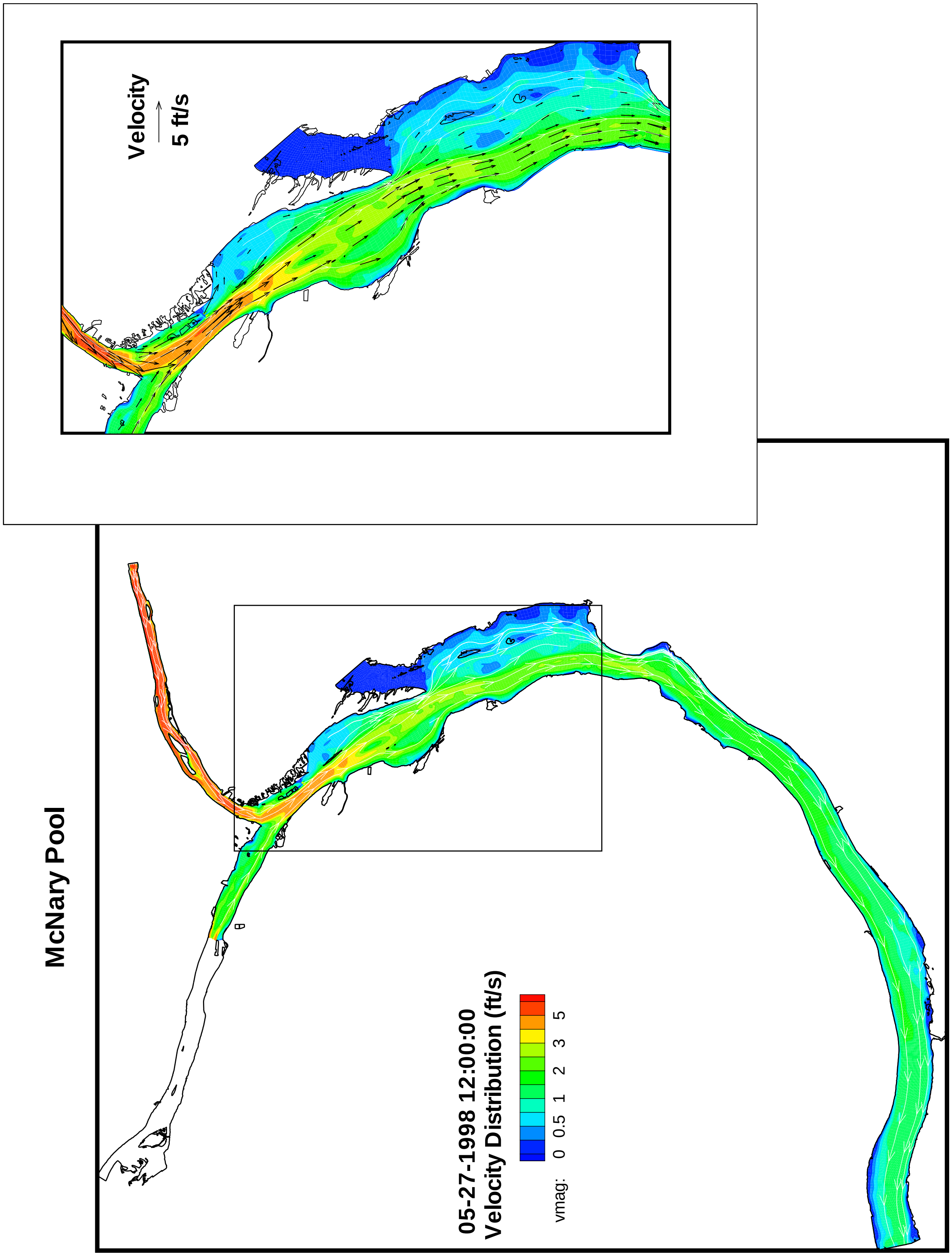

Figure 5.4: Velocity distribution generated by MASS2 showing streamlines and velocity vectors (inset).

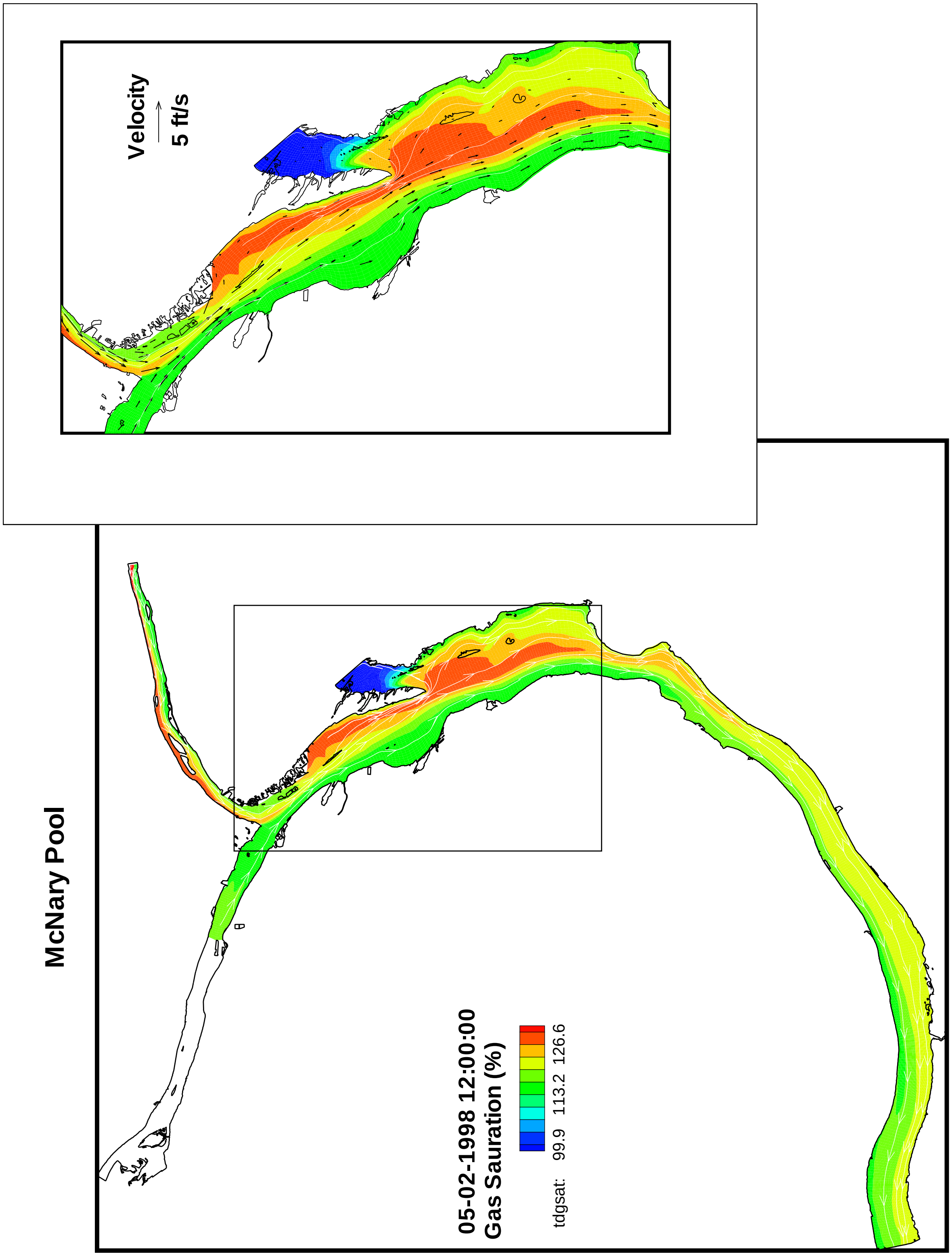

Figure 5.5: Distribution of percent gas saturation generated by MASS2 showing streamlines and velocity vectors (inset).

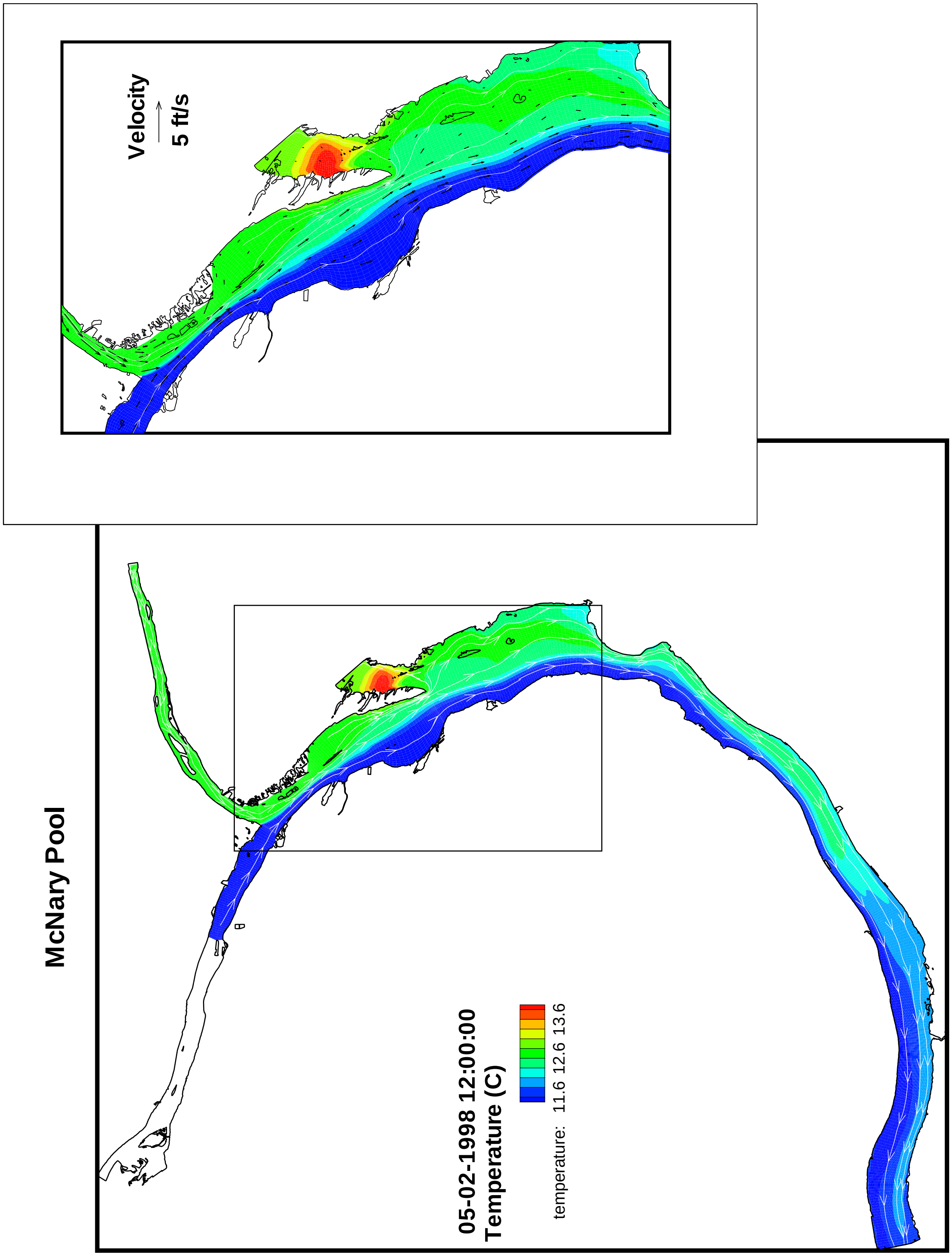

Figure 5.6: Distribution of water temperature generated by MASS2 showing streamlines and velocity vectors (inset).

5.2 FINS Model Runs

Model parameters for FINS example runs are based on the application of FINS-INV to hourly radiotelemetry data from 1997 and 1998, and on analysis of depth variations in one-minute radiotelemetry observations from the same years, as described in chapters 2 and 3 above, respectively. The model parameters are tabulated in tables 2.1 and 3.1 above.

For each year (1997 and 1998) and species (HSPC and STHD), 25 simulated fish were released at midstream of the top of the reach immediately downstream of Ice Harbor Dam, at the water surface. Simulated fish were released at midnight of May 15 in 1997 and midnight of May 14, 1998 (during the high-flow period in both years), and tracked for a 24-hour period. Unsteady flow conditions from the MASS2 hydrodynamic code were updated on half-hour intervals throughout the simulation periods.

Graphical results from each of the four cases considered are presented below. For each case, we show the locations of the 25 simulated fish at six selected times: 1, 3, 6, 9, 15, and 20 hours after release. The temperature and dissolved gas level experienced by each simulated fish is also indicated by color coding. Graphs of complete time history of fish depth and dissolved gas exposure are presented for 2 of the 25 fish, for each case. Note that, although dissolved gas concentrations are expressed here in terms of percent saturation for simplicity of presentation, FINS can calculate and output depth-compensated excess gas pressures (e.g., compensated for hydrostatic water pressure as a function of fish depth), which is a more directly useful metric for estimating the likelihood of gas bubble trauma effects. A comparison of the observed and simulated distribution of fish depth is also presented for each case.

5.2.1 Case1: HSPC 1997

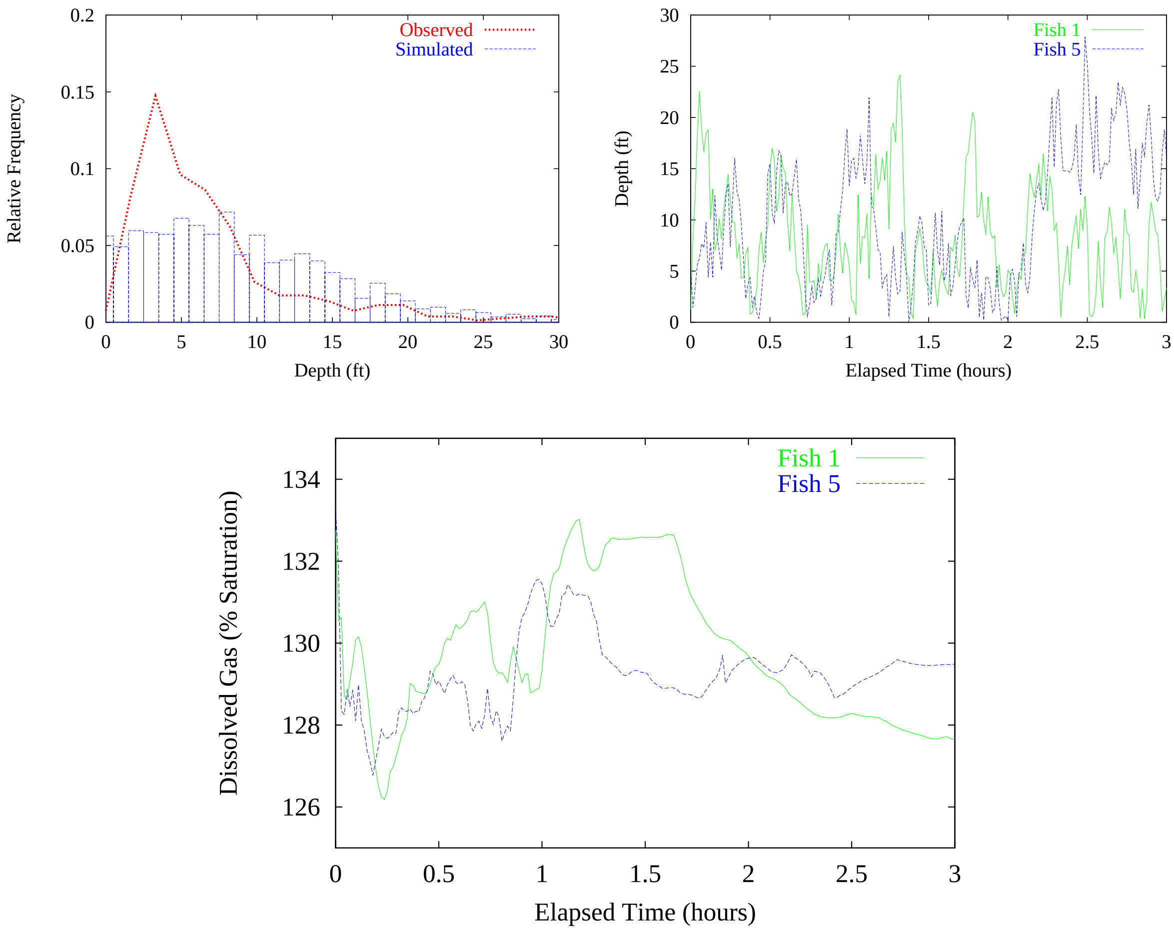

Figure 5.7: Graphical summaries of FINS model results for Case 1 (HSPC 1997). Top left: Comparison of observed and simulated distributions of smolt depth. Top right: Simulated depth traces for two selected fish. Bottom: Simulated dissolved gas histories for two selected fish.

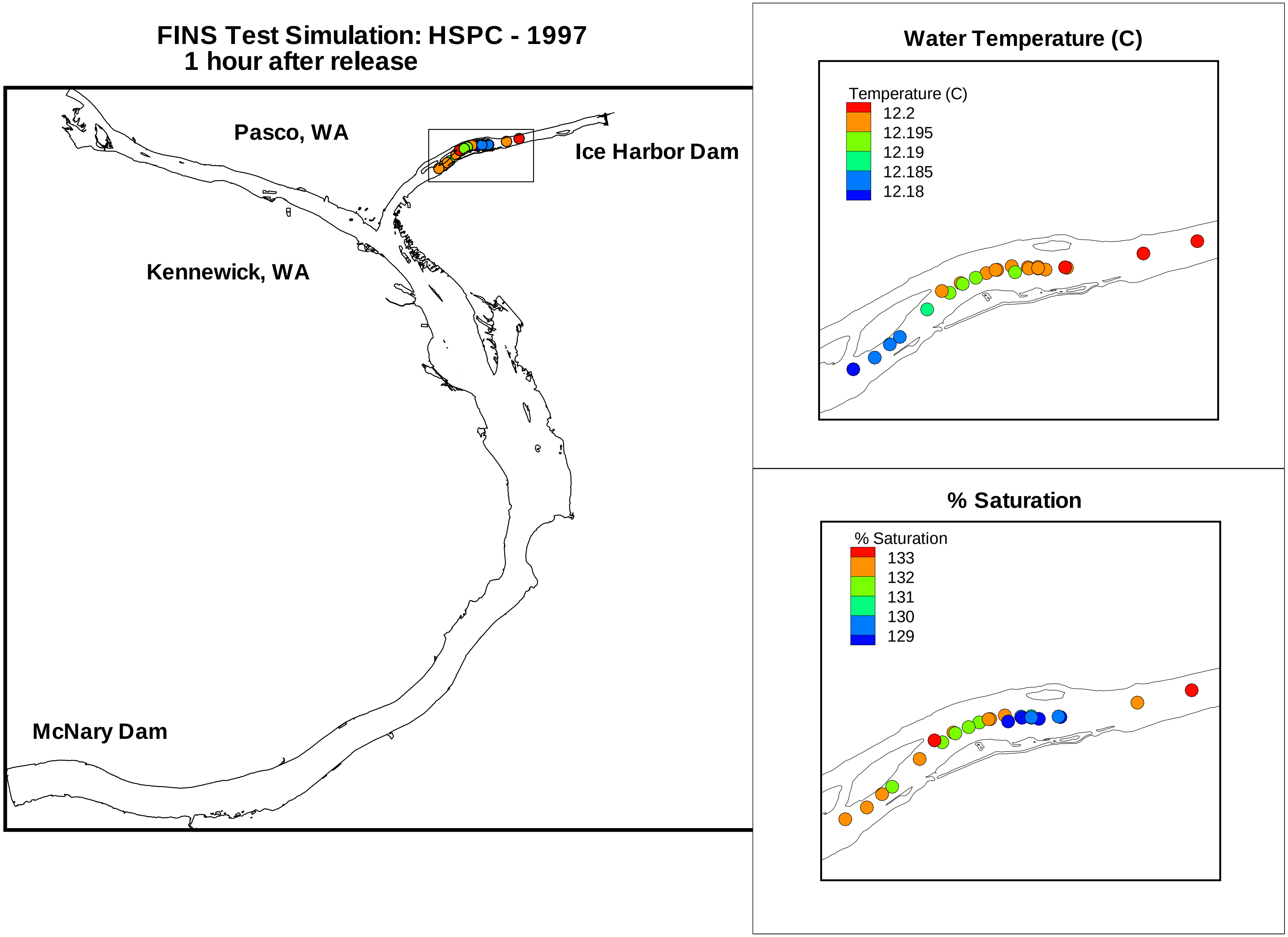

Figure 5.8: Location, local temperature, and total dissolved gas saturation levels of twenty simulated fish particles, 1 hour after release in the Ice Harbor tailrace. Fish movement parameters derived for hatchery Spring Chinook during the 1997 migration season were used

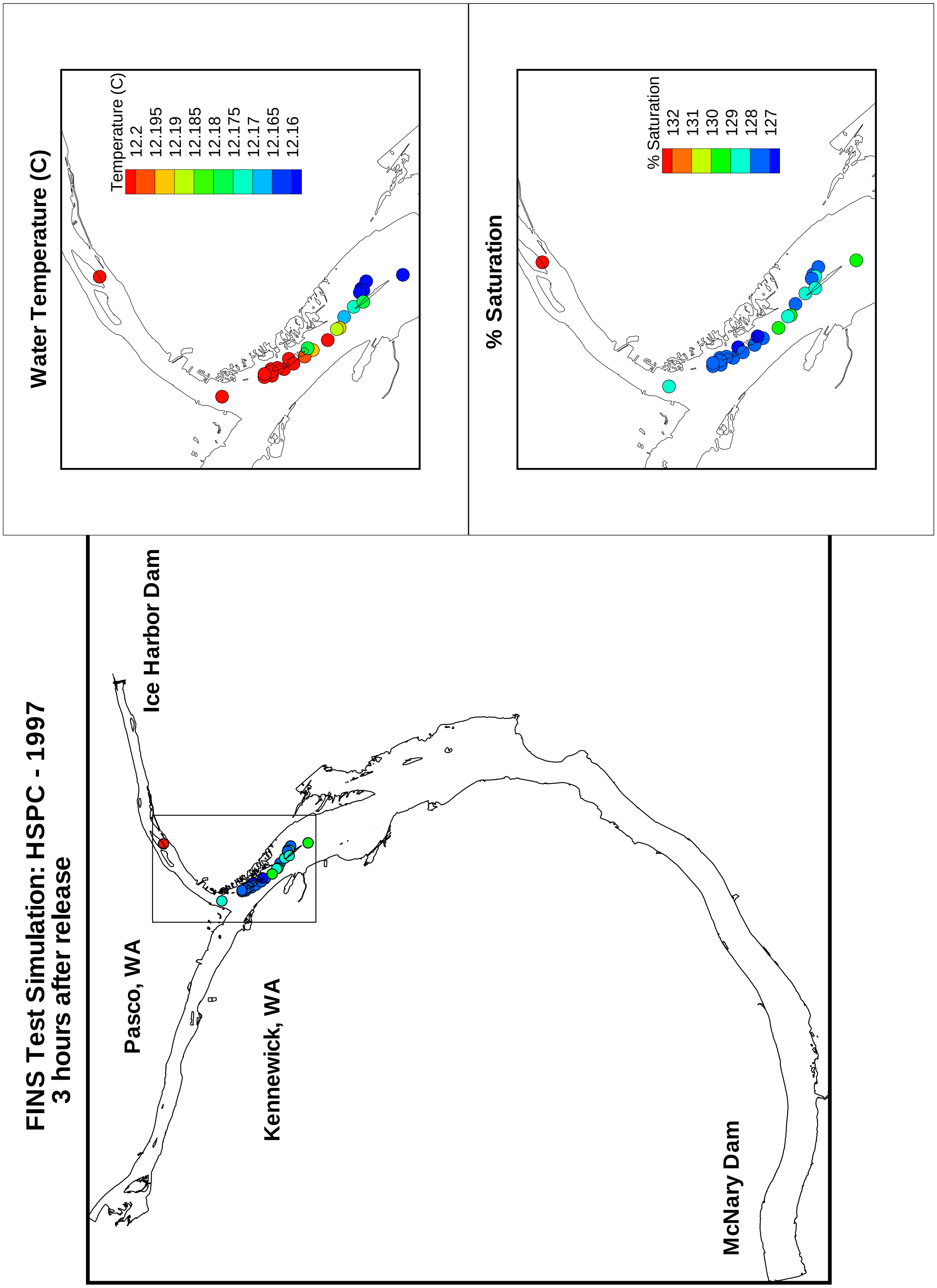

Figure 5.9: Location, local temperature, and total dissolved gas saturation levels of twenty simulated fish particles, 3 hours after release in the Ice Harbor tailrace. Fish movement parameters derived for hatchery Spring Chinook during the 1997 migration season were used

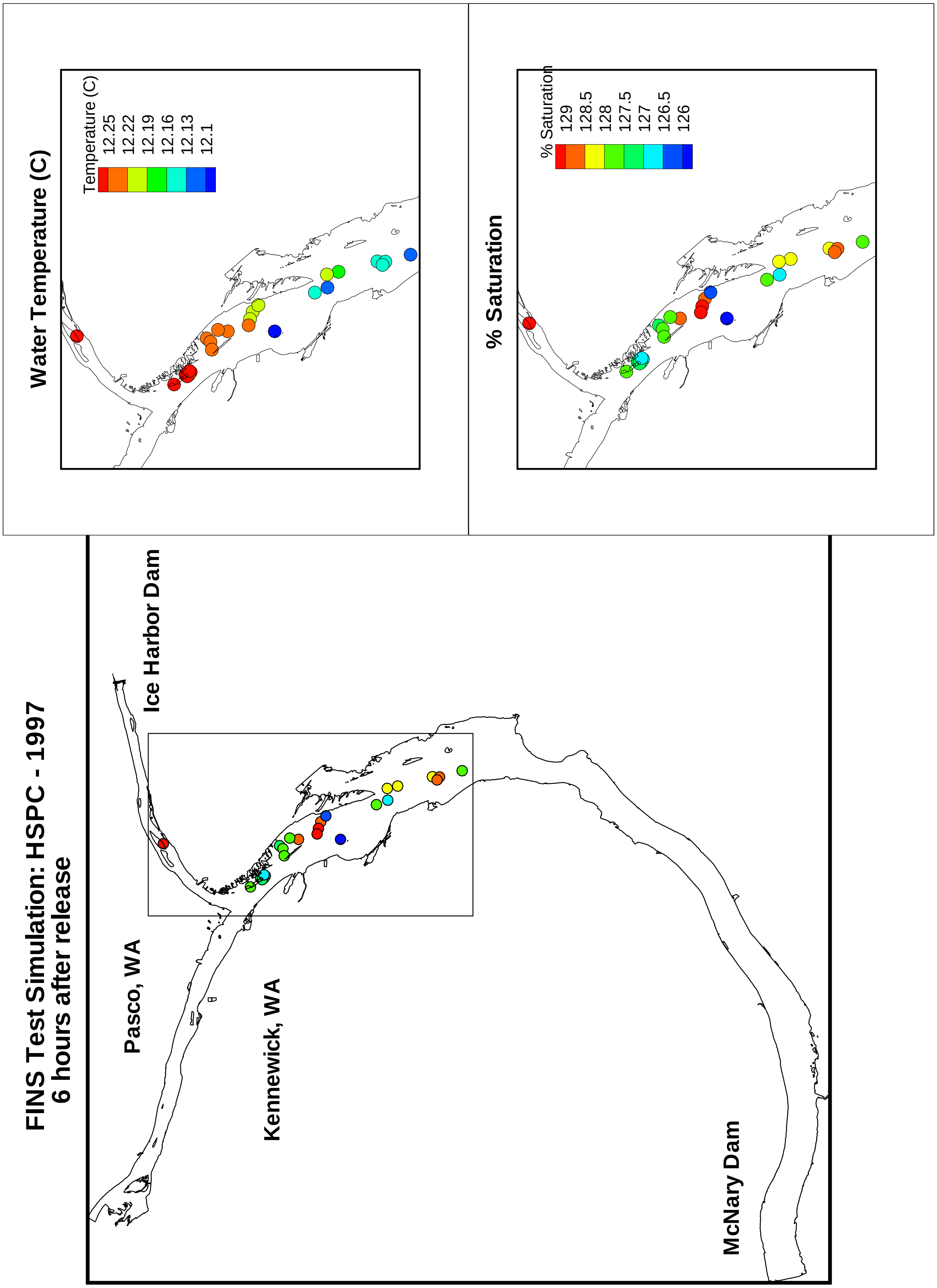

Figure 5.10: Location, local temperature, and total dissolved gas saturation levels of twenty simulated fish particles, 6 hours after release in the Ice Harbor tailrace. Fish movement parameters derived for hatchery Spring Chinook during the 1997 migration season were used

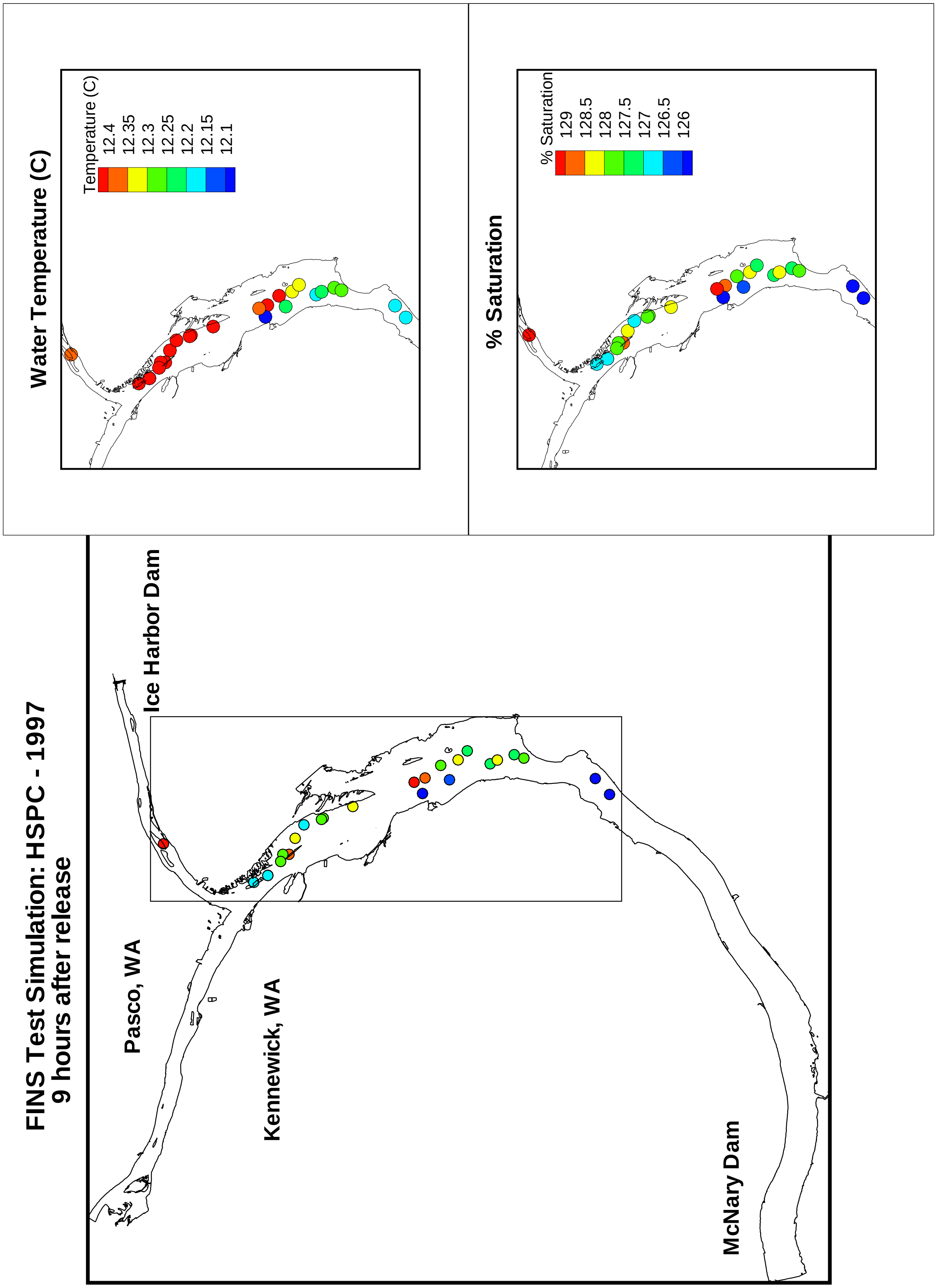

Figure 5.11: Location, local temperature, and total dissolved gas saturation levels of twenty simulated fish particles, 9 hours after release in the Ice Harbor tailrace. Fish movement parameters derived for hatchery Spring Chinook during the 1997 migration season were used

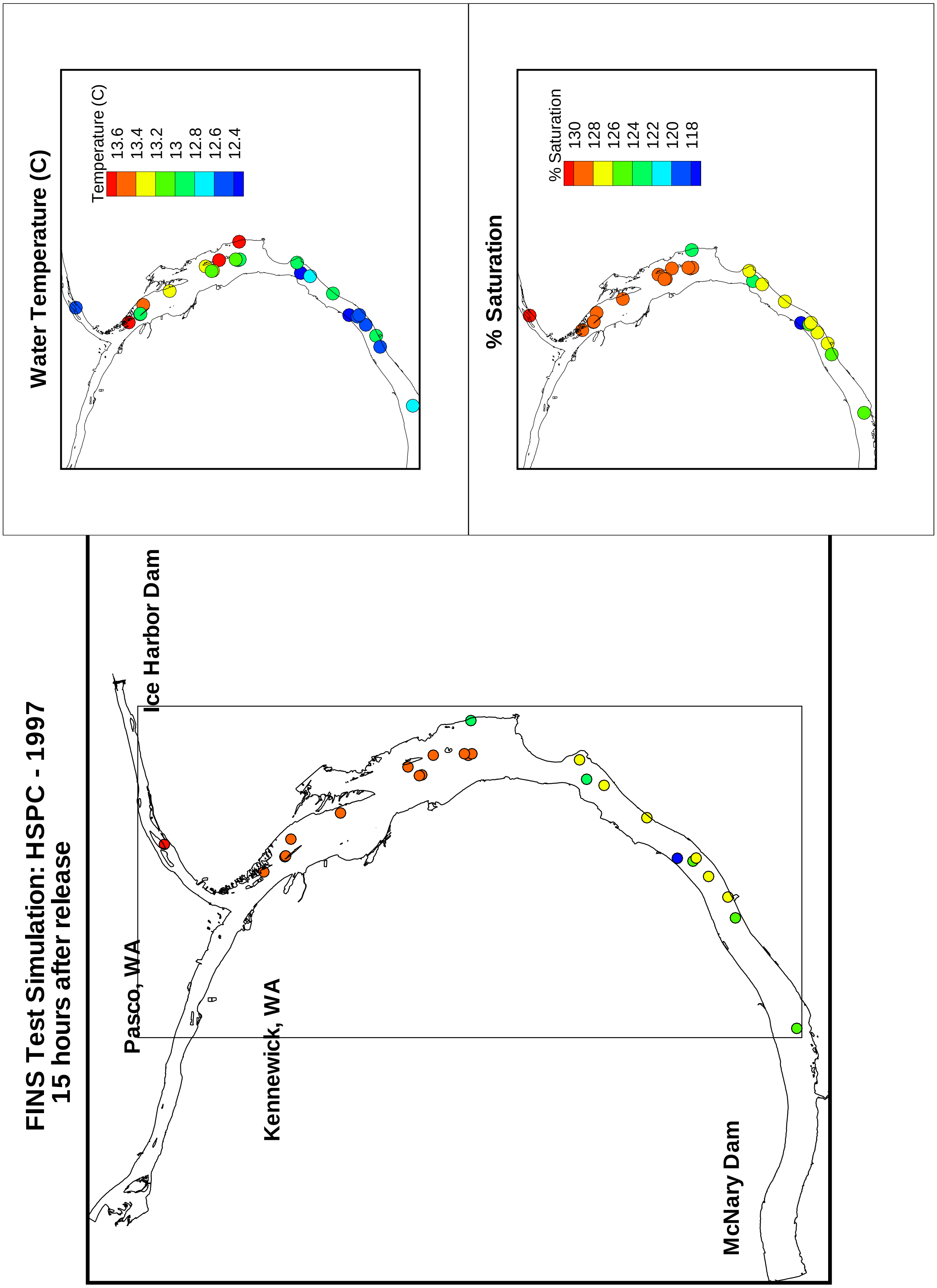

Figure 5.12: Location, local temperature, and total dissolved gas saturation levels of twenty simulated fish particles, 15 hours after release in the Ice Harbor tailrace. Fish movement parameters derived for hatchery Spring Chinook during the 1997 migration season were used

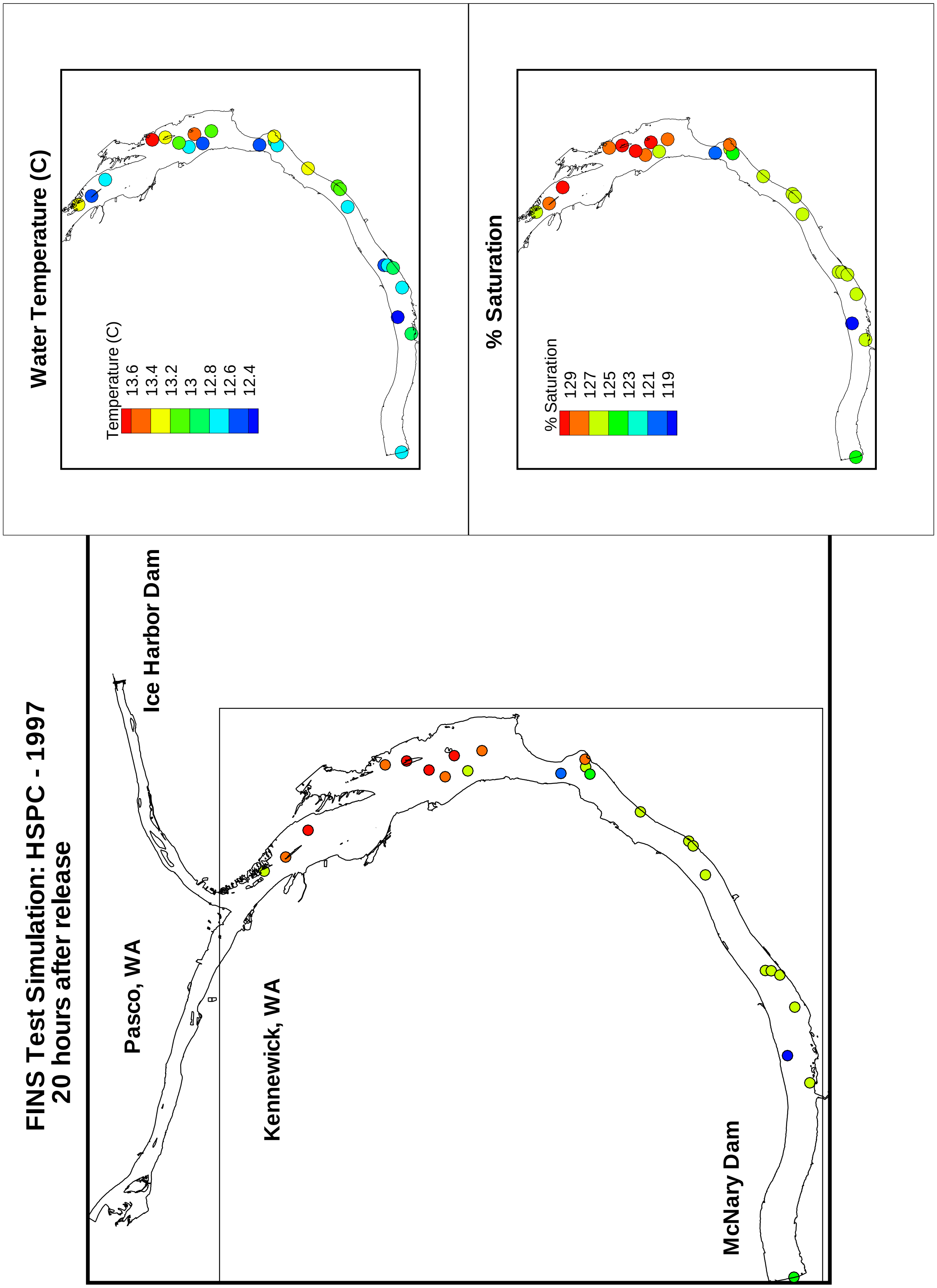

Figure 5.13: Location, local temperature, and total dissolved gas saturation levels of twenty simulated fish particles, 20 hours after relaease in the Ice Harbor tailrace. Fish movement parameters derived for hatchery Spring Chinook during the 1997 migration season were used

5.2.2 Case2: HSPC 1998

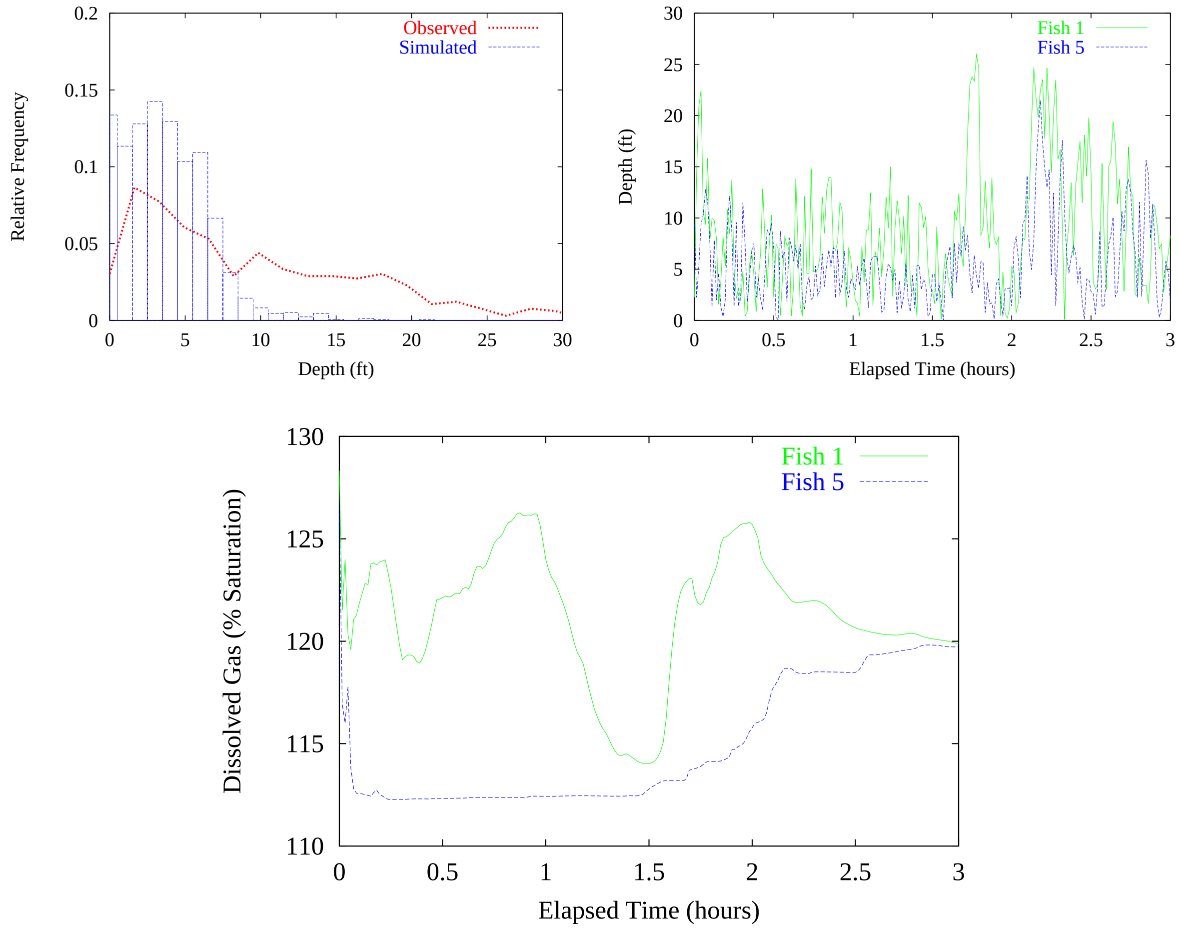

Figure 5.14: Graphical summaries of FINS model results for Case 2 (HSPC 1998). Top left: Comparison of observed and simulated distributions of smolt depth. Top right: Simulated depth traces for two selected fish. Bottom: Simulated dissolved gas histories for two selected fish.

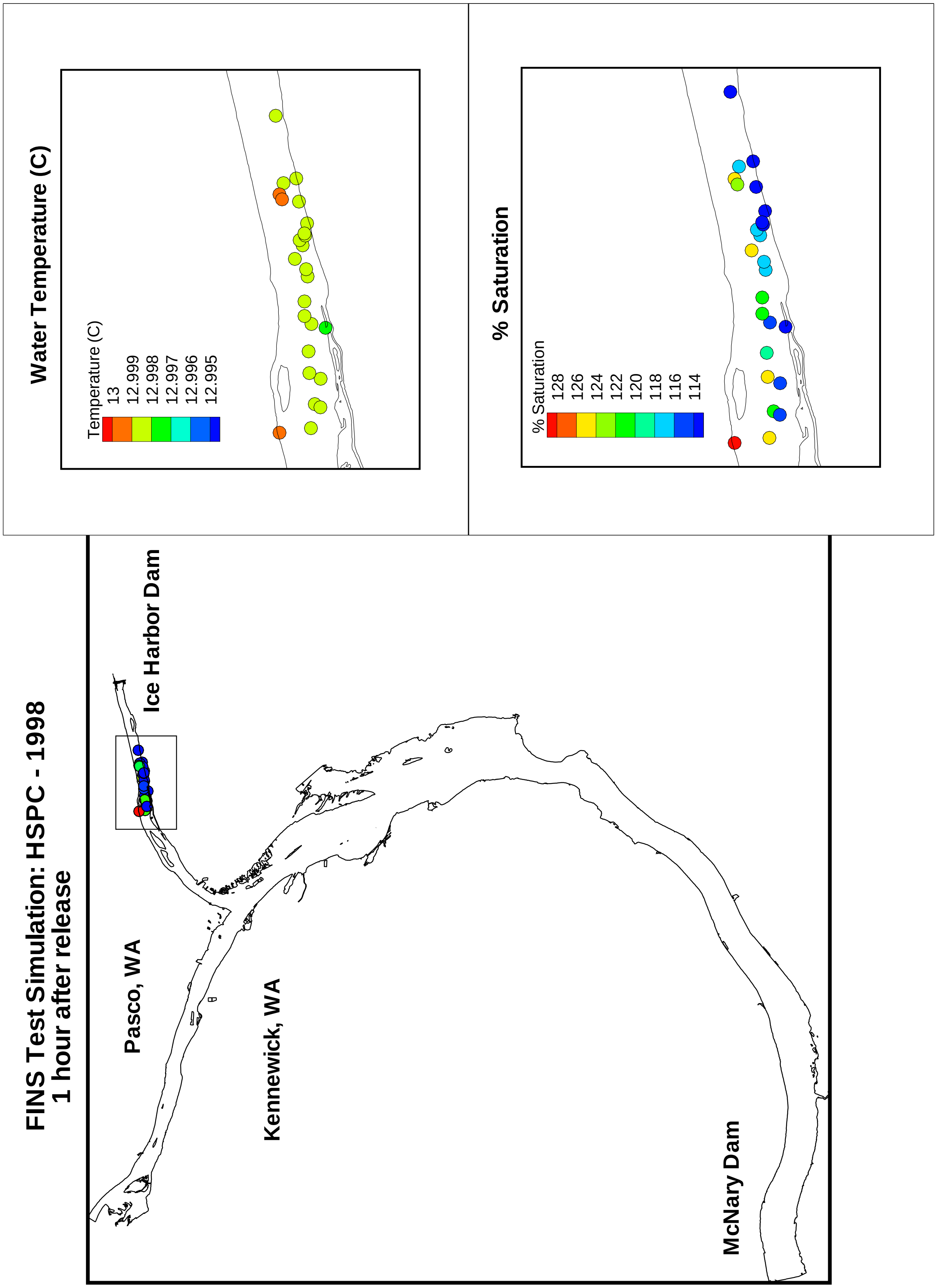

Figure 5.15: Location, local temperature, and total dissolved gas saturation levels of twenty simulated fish particles, 1 hour after relaease in the Ice Harbor tailrace. Fish movement parameters derived for hatchery Spring Chinook during the 1998 migration season were used

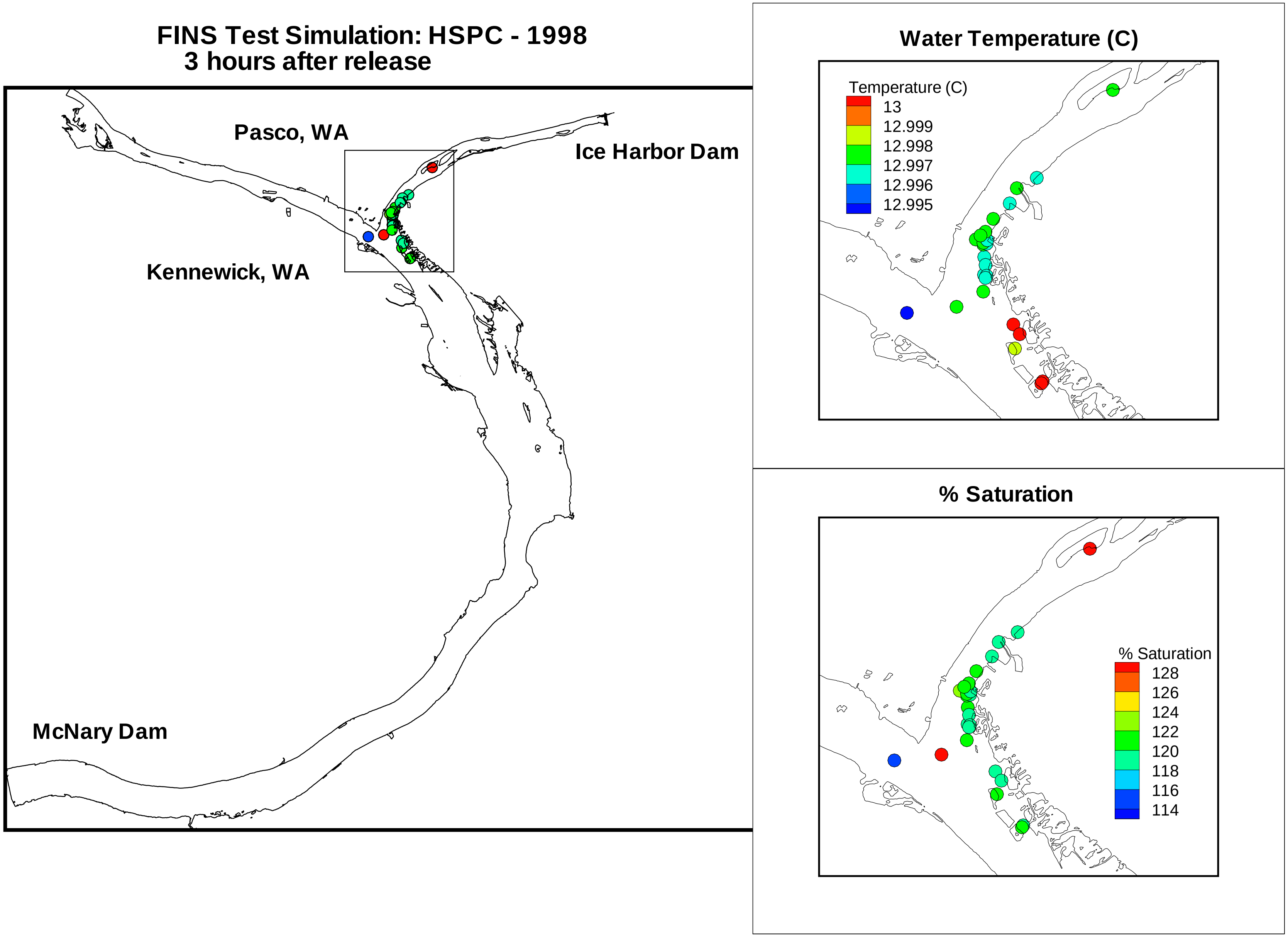

Figure 5.16: Location, local temperature, and total dissolved gas saturation levels of twenty simulated fish particles, 3 hours after relaease in the Ice Harbor tailrace. Fish movement parameters derived for hatchery Spring Chinook during the 1998 migration season were used

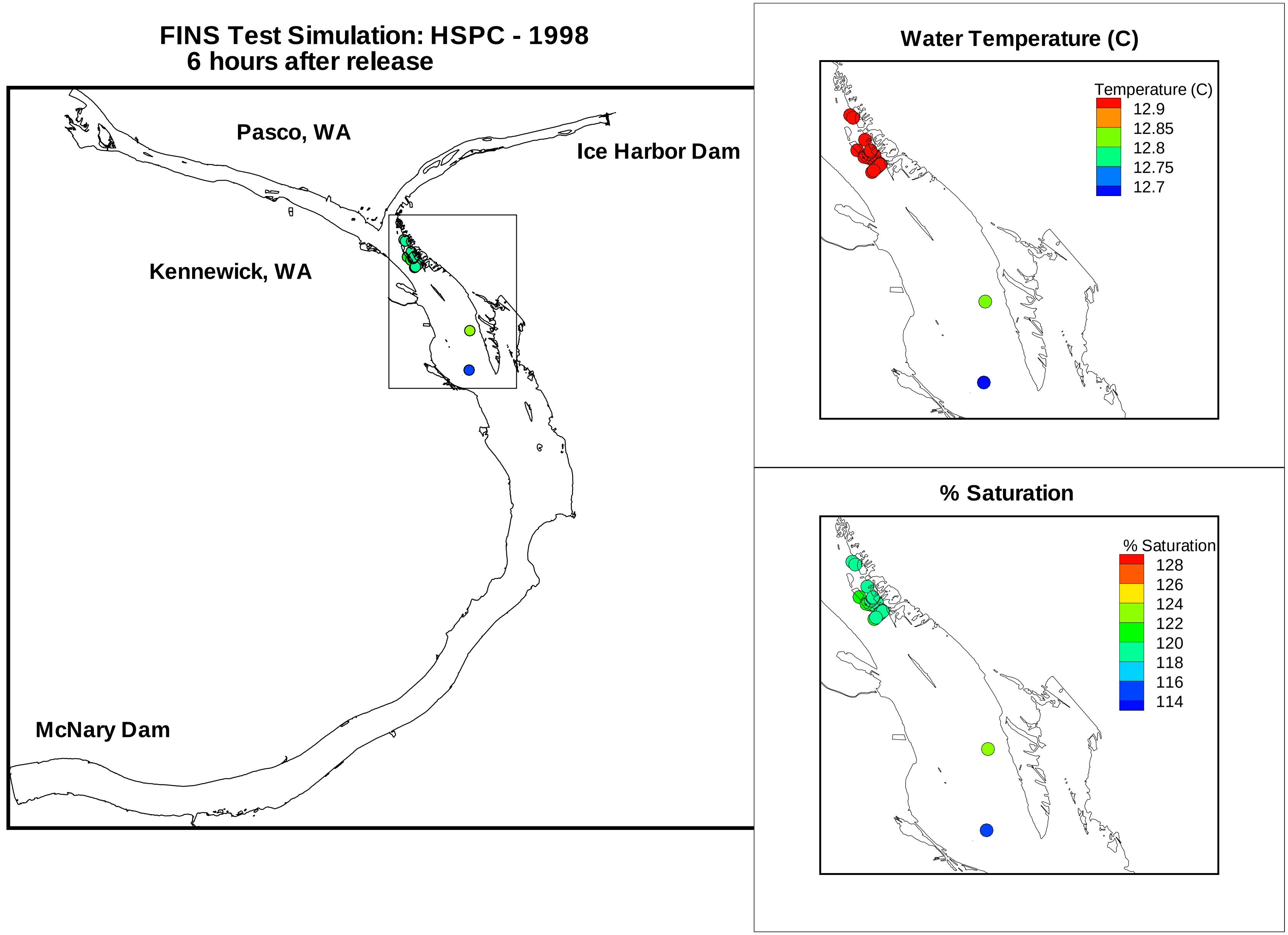

Figure 5.17: Location, local temperature, and total dissolved gas saturation levels of twenty simulated fish particles, 6 hours after relaease in the Ice Harbor tailrace. Fish movement parameters derived for hatchery Spring Chinook during the 1998 migration season were used

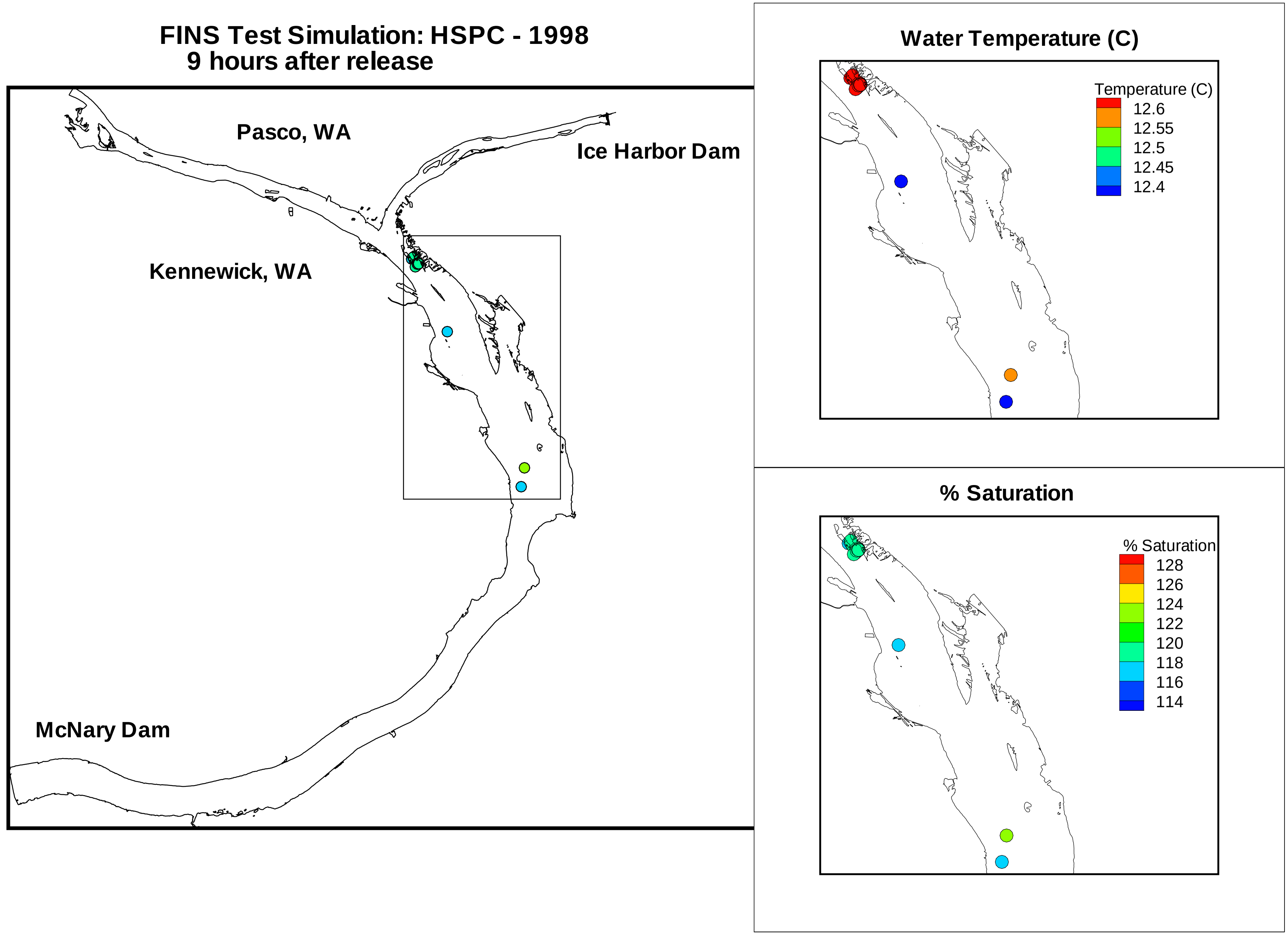

Figure 5.18: Location, local temperature, and total dissolved gas saturation levels of twenty simulated fish particles, 9 hours after relaease in the Ice Harbor tailrace. Fish movement parameters derived for hatchery Spring Chinook during the 1998 migration season were used

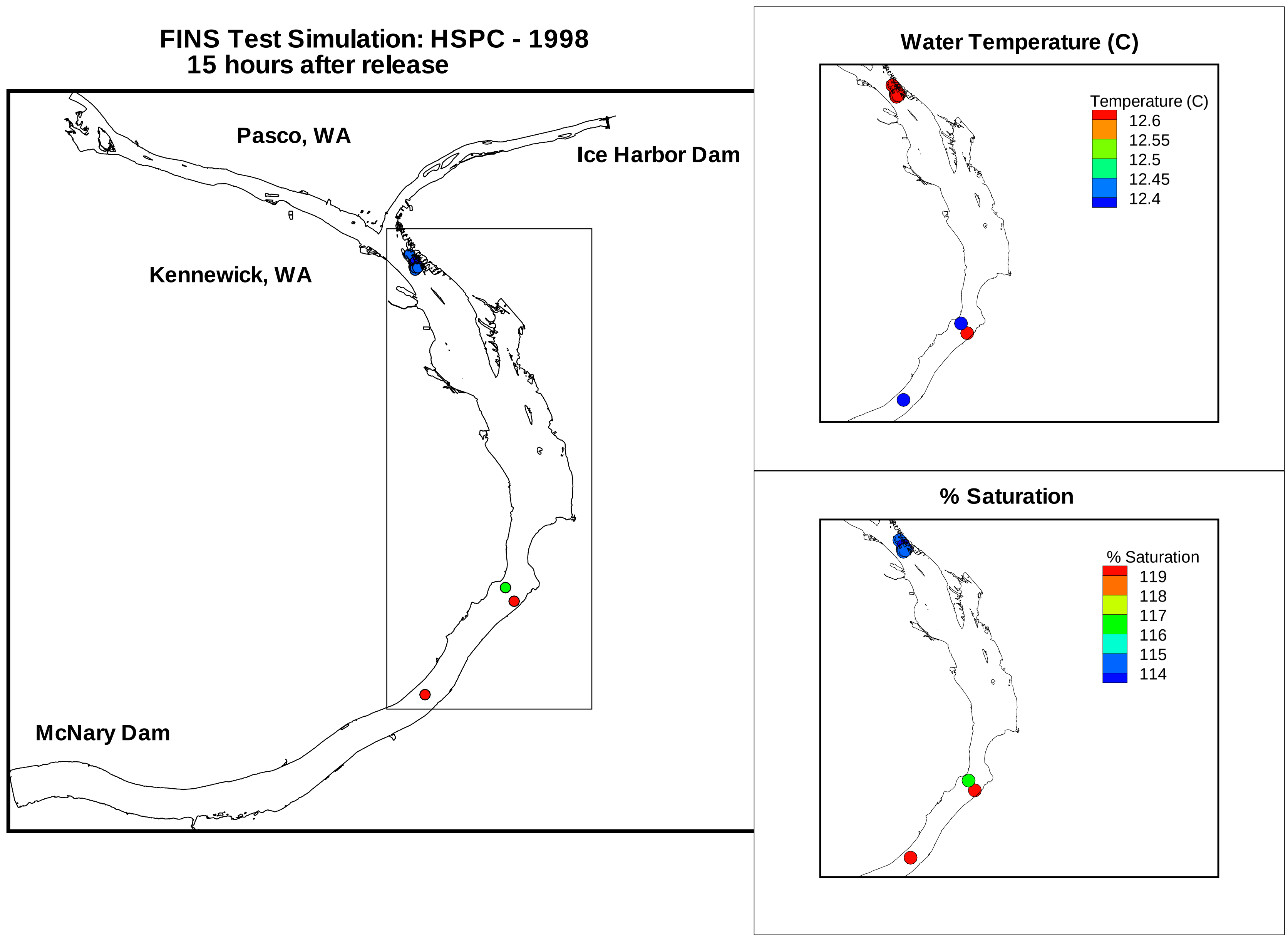

Figure 5.19: Location, local temperature, and total dissolved gas saturation levels of twenty simulated fish particles, 15 hours after relaease in the Ice Harbor tailrace. Fish movement parameters derived for hatchery Spring Chinook during the 1998 migration season were used

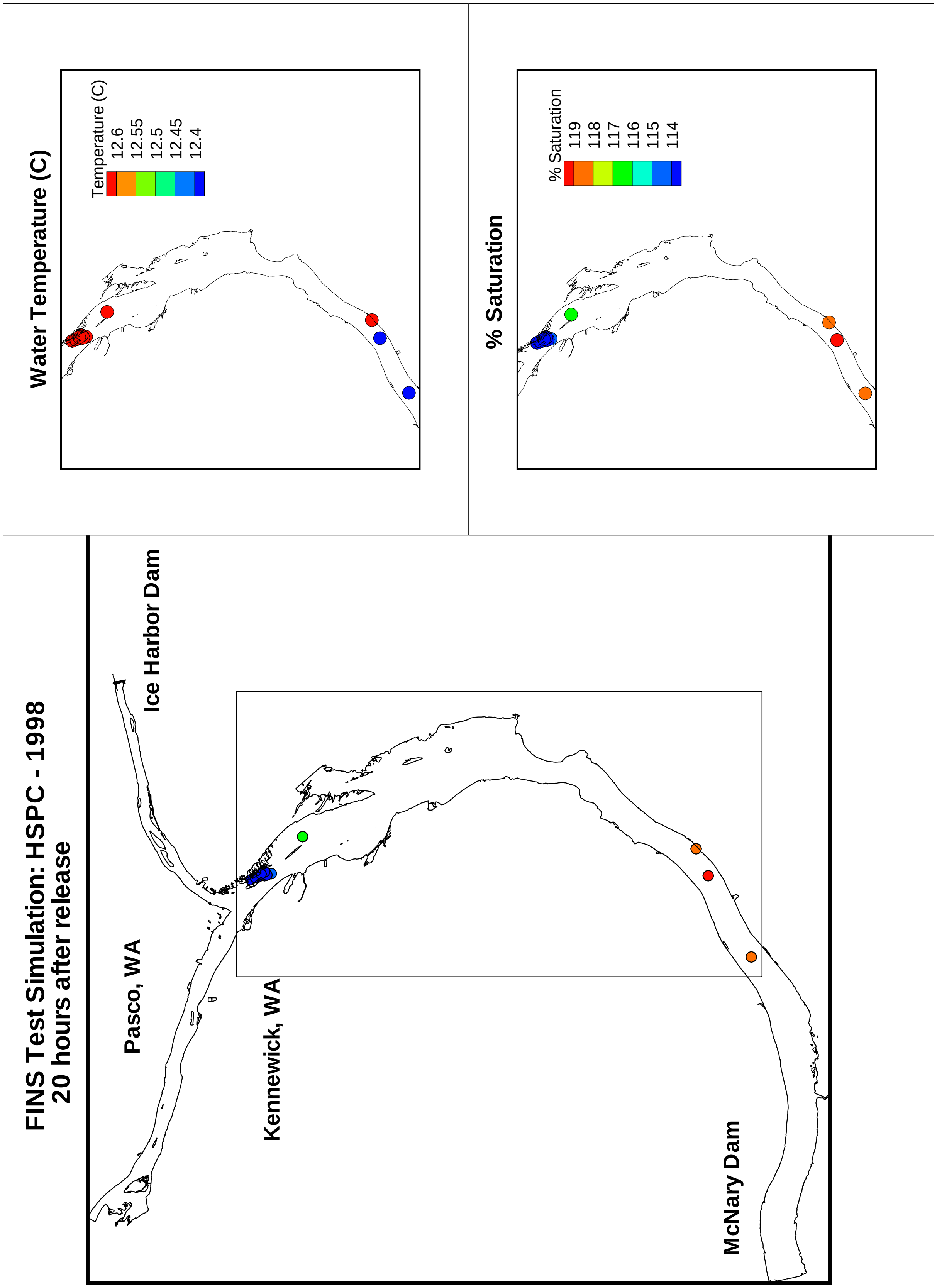

Figure 5.20: Location, local temperature, and total dissolved gas saturation levels of twenty simulated fish particles, 20 hours after relaease in the Ice Harbor tailrace. Fish movement parameters derived for hatchery Spring Chinook during the 1998 migration season were used

5.2.3 Case3: STHD 1997

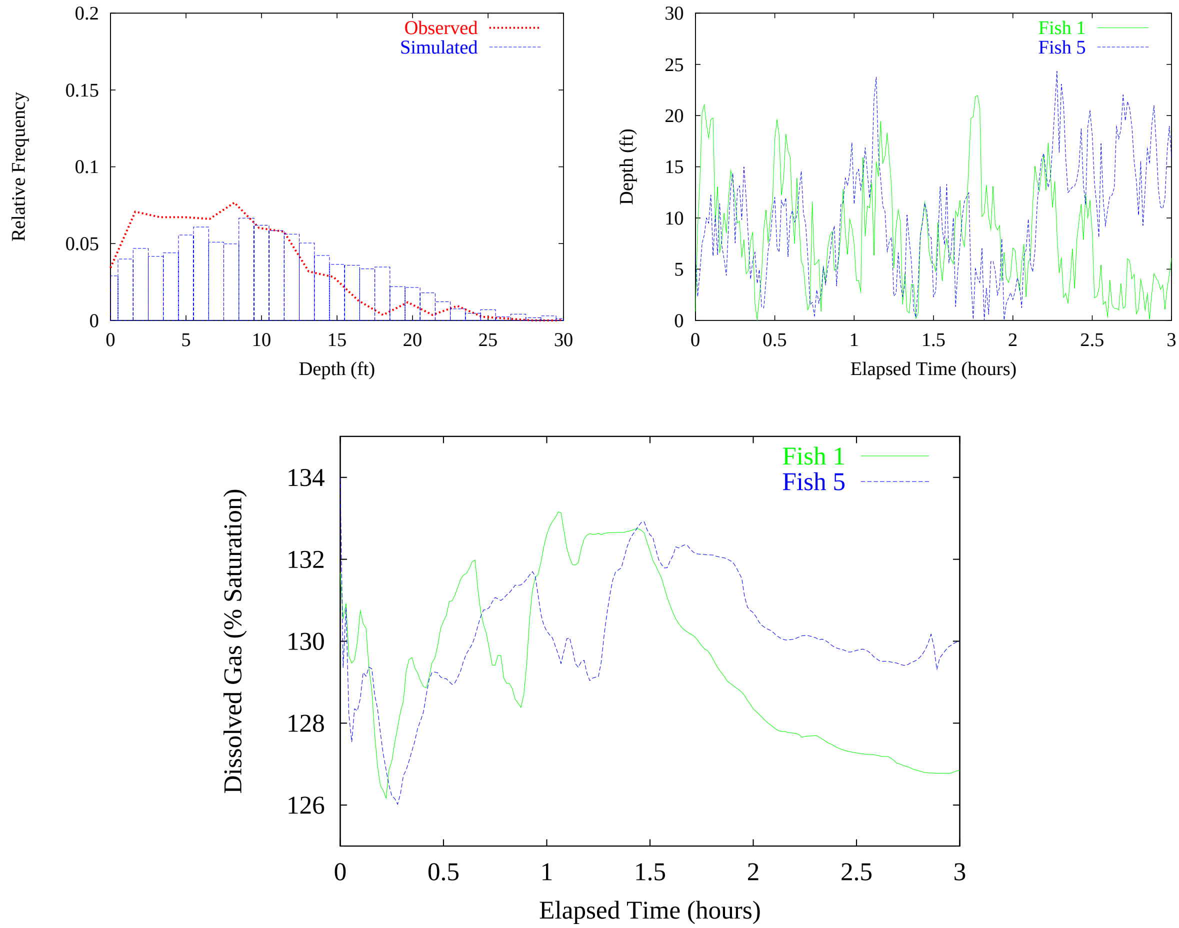

Figure 5.21: Graphical summaries of FINS model results for Case 3 (STHD 1997). Top left: Comparison of observed and simulated distributions of smolt depth. Top right: Simulated depth traces for two selected fish. Bottom: Simulated dissolved gas histories for two selected fish.

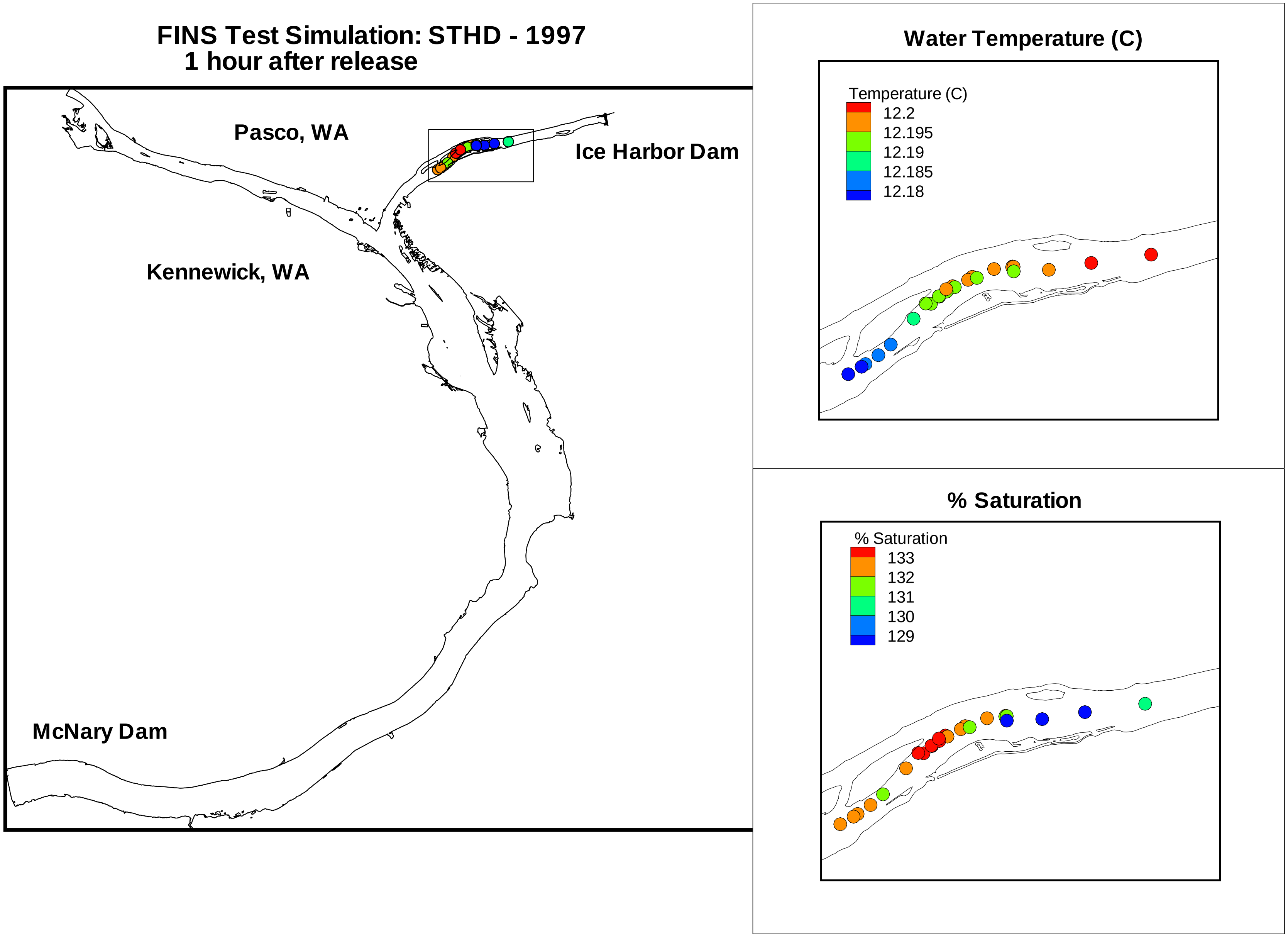

Figure 5.22: Location, local temperature, and total dissolved gas saturation levels of twenty simulated fish particles, 1 hour after relaease in the Ice Harbor tailrace. Fish movement parameters derived for hatchery Steelhead during the 1997 migration season were used

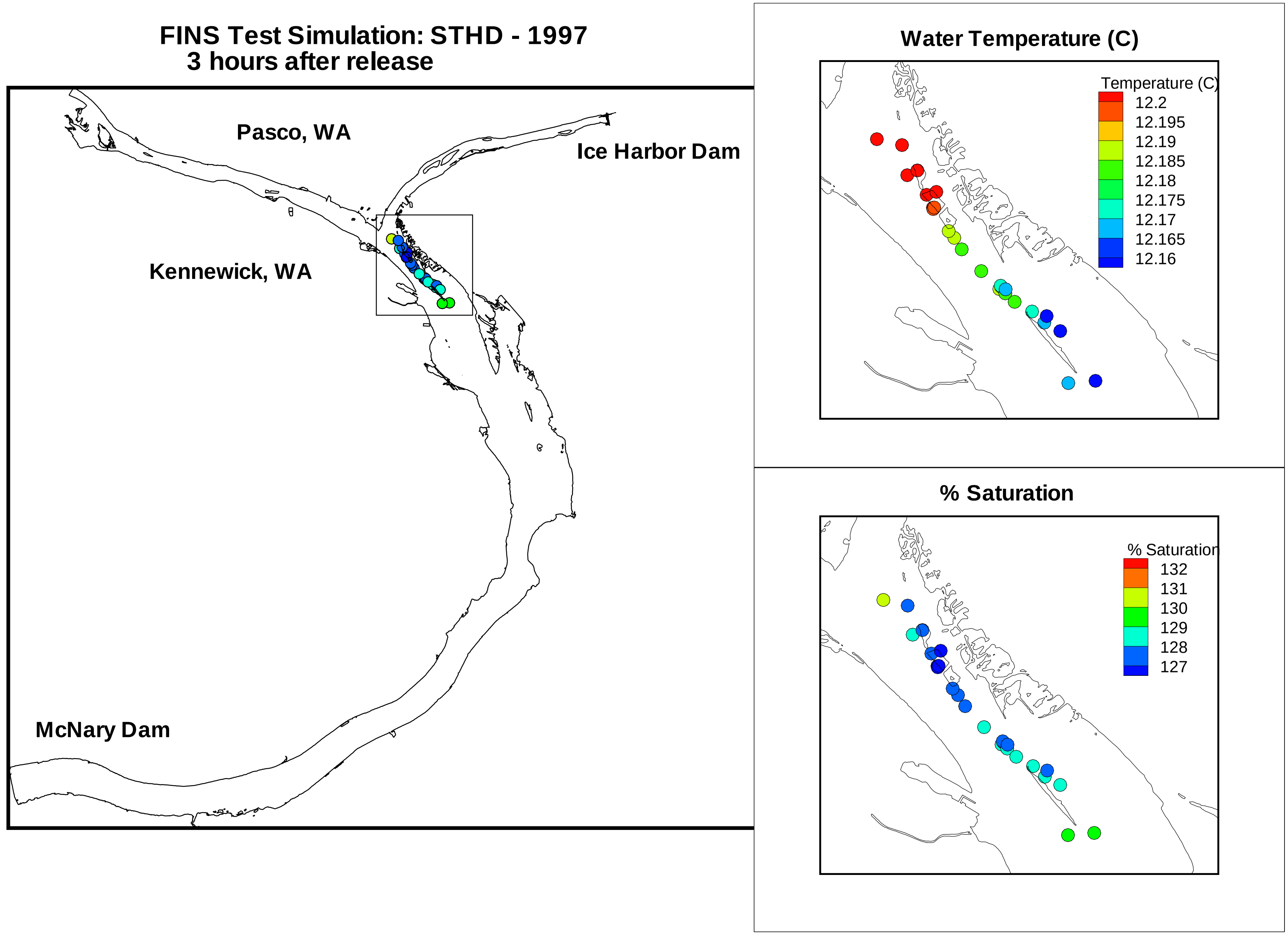

Figure 5.23: Location, local temperature, and total dissolved gas saturation levels of twenty simulated fish particles, 1 hour after relaease in the Ice Harbor tailrace. Fish movement parameters derived for hatchery Steelhead during the 1997 migration season were used

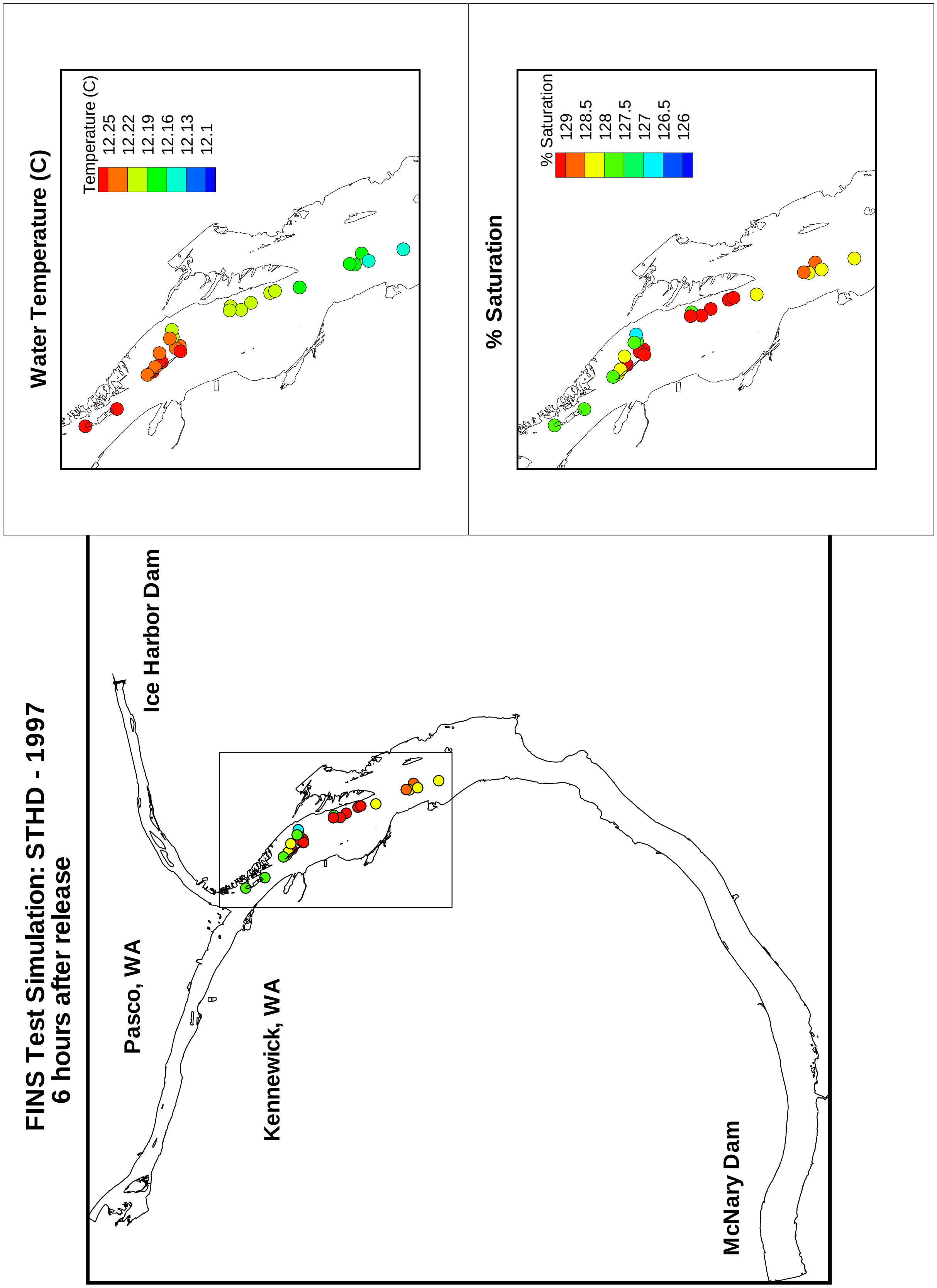

Figure 5.24: Location, local temperature, and total dissolved gas saturation levels of twenty simulated fish particles, 6 hours after relaease in the Ice Harbor tailrace. Fish movement parameters derived for hatchery Steelhead during the 1997 migration season were used

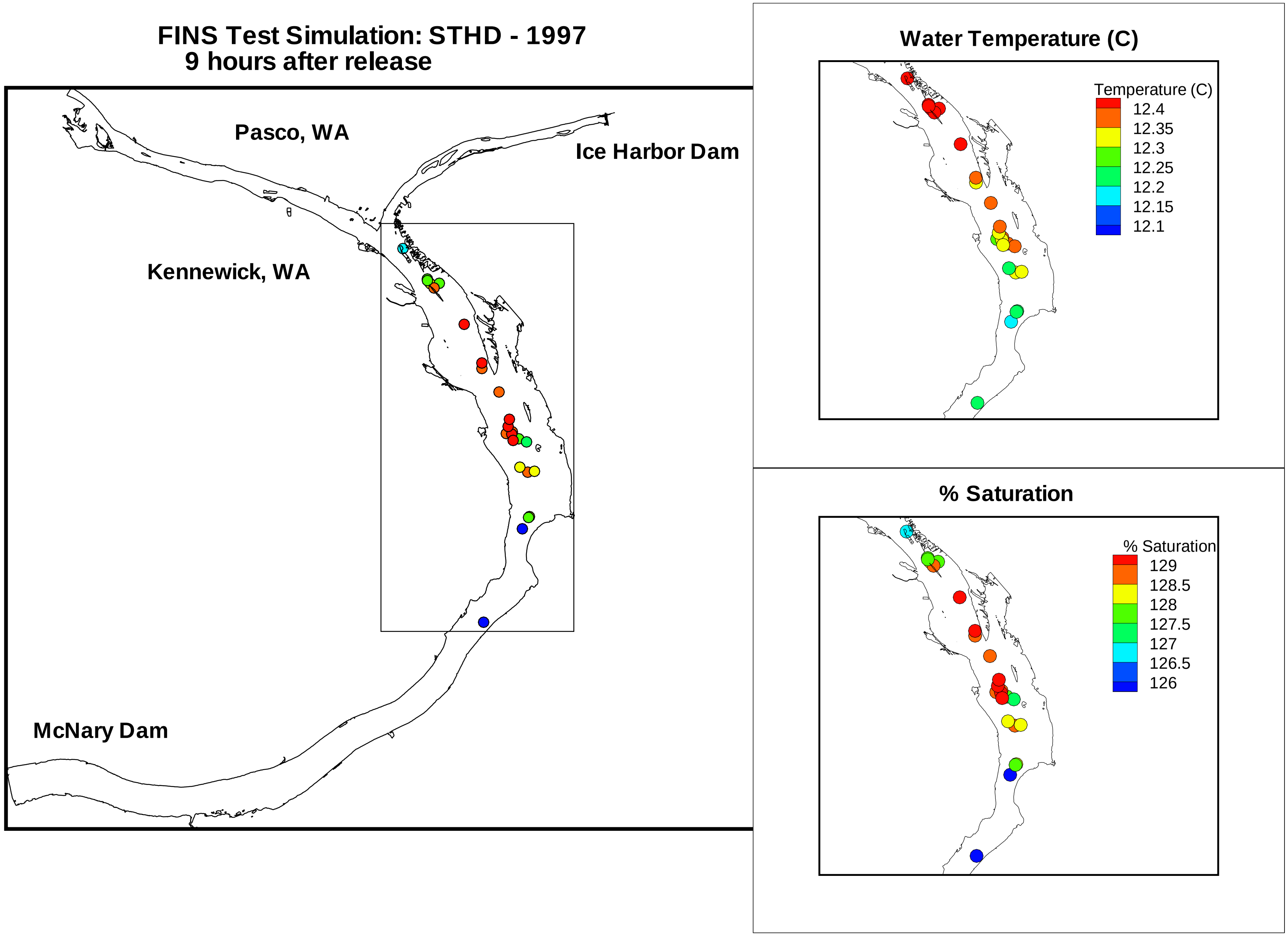

Figure 5.25: Location, local temperature, and total dissolved gas saturation levels of twenty simulated fish particles, 9 hours after relaease in the Ice Harbor tailrace. Fish movement parameters derived for hatchery Steelhead during the 1997 migration season were used

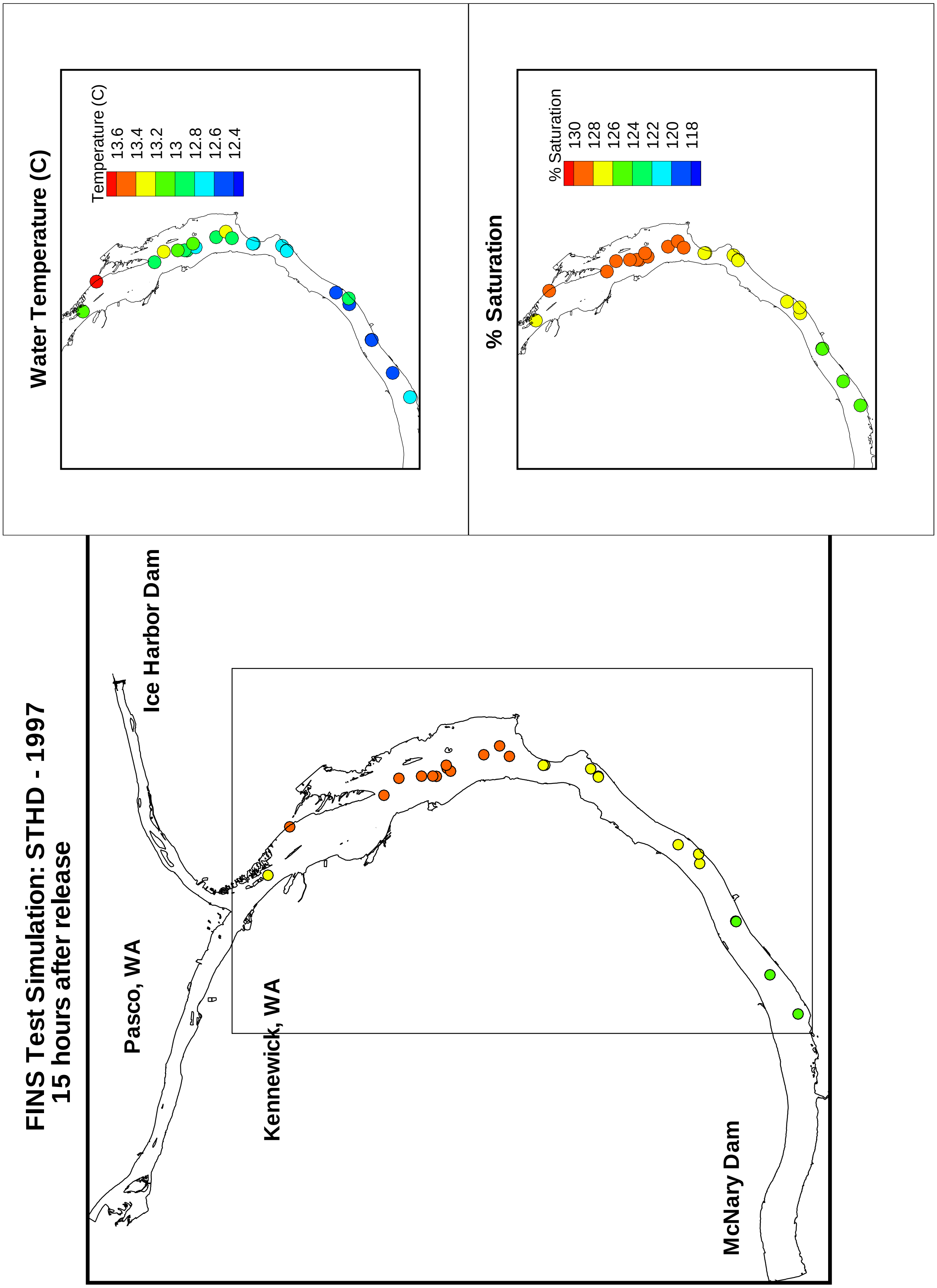

Figure 5.26: Location, local temperature, and total dissolved gas saturation levels of twenty simulated fish particles, 15 hours after relaease in the Ice Harbor tailrace. Fish movement parameters derived for hatchery Steelhead during the 1997 migration season were used

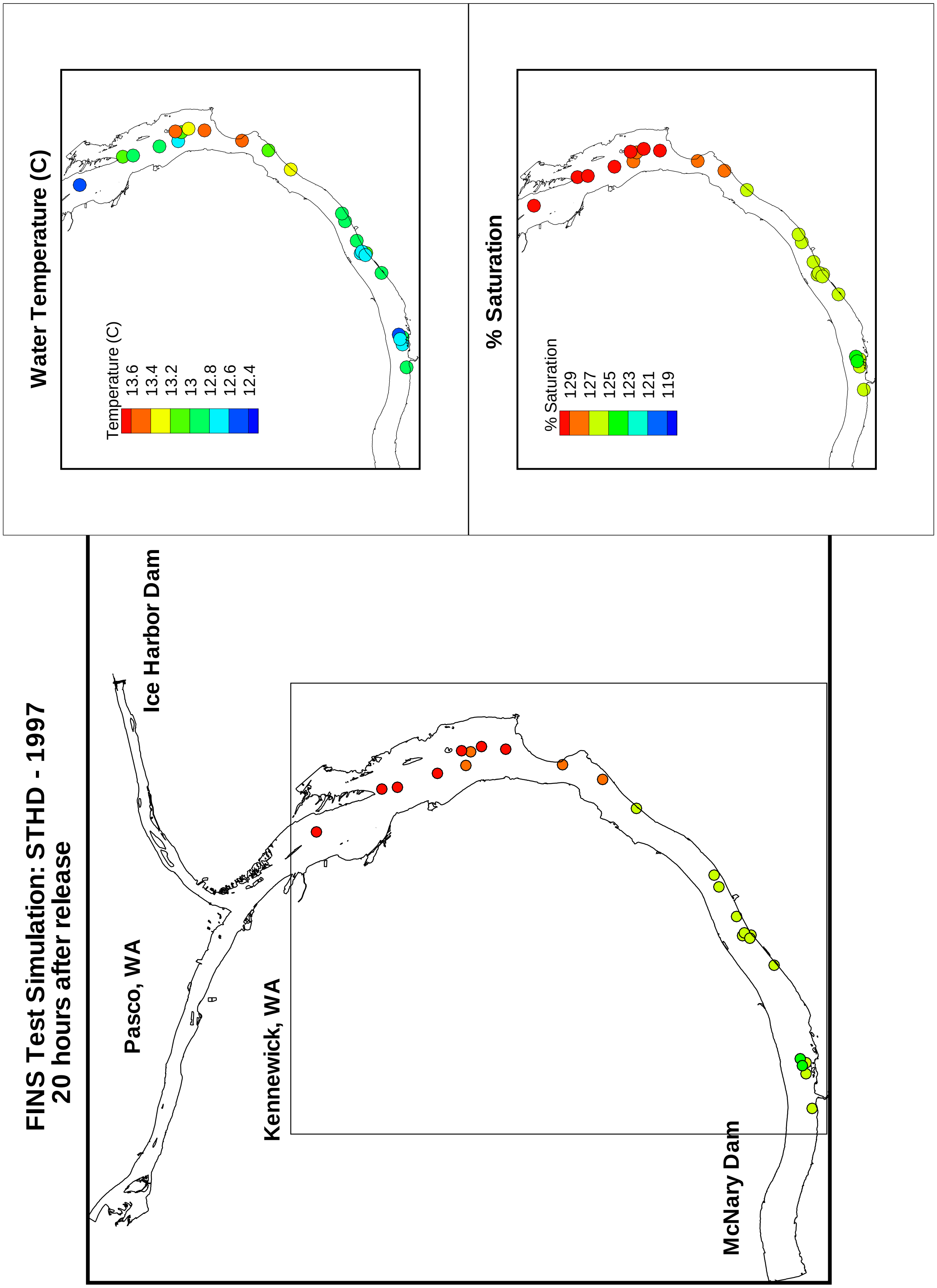

Figure 5.27: Location, local temperature, and total dissolved gas saturation levels of twenty simulated fish particles, 20 hours after relaease in the Ice Harbor tailrace. Fish movement parameters derived for hatchery Steelhead during the 1997 migration season were used

5.2.4 Case4: STHD 1998

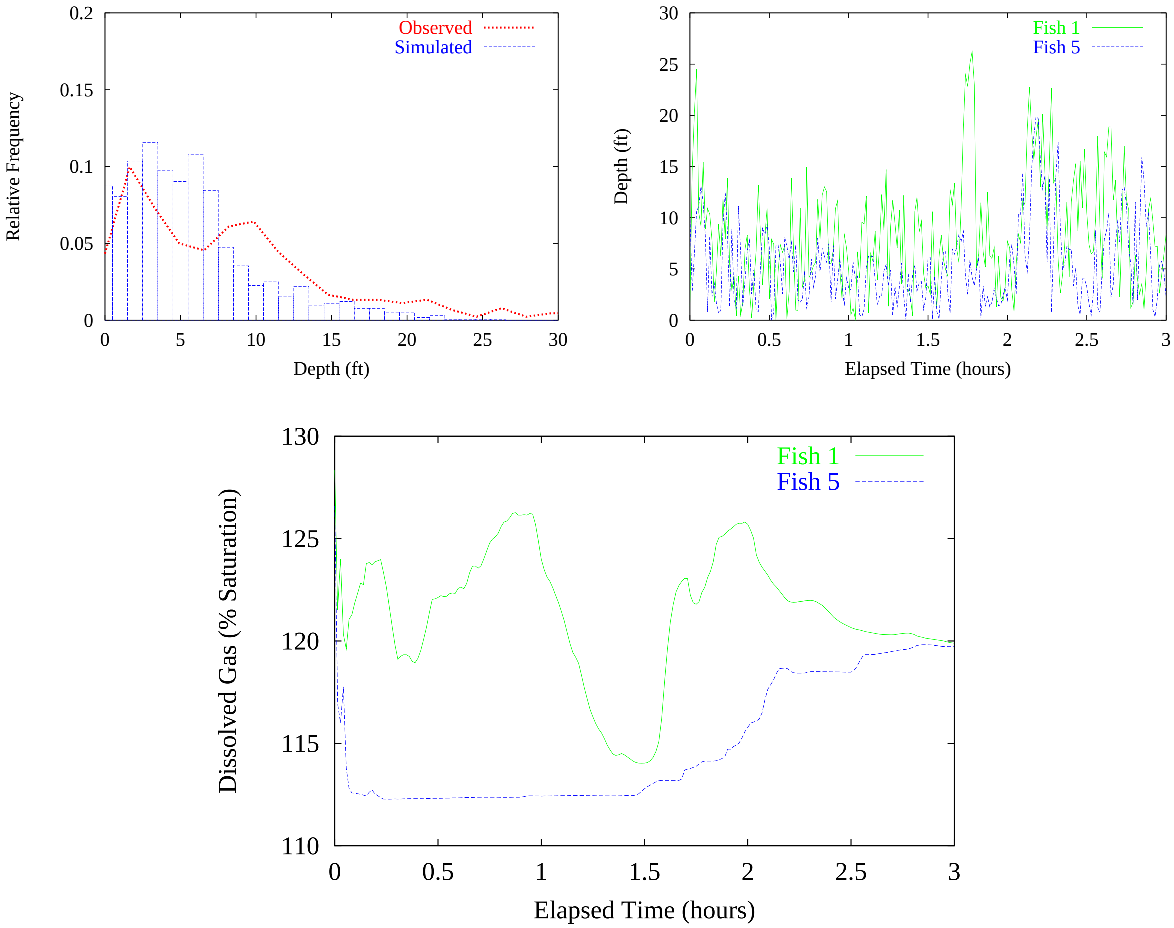

Figure 5.28: Graphical summaries of FINS model results for Case 4 (STHD 1998). Top left: Comparison of observed and simulated distributions of smolt depth. Top right: Simulated depth traces for two selected fish. Bottom: Simulated dissolved gas histories for two selected fish.

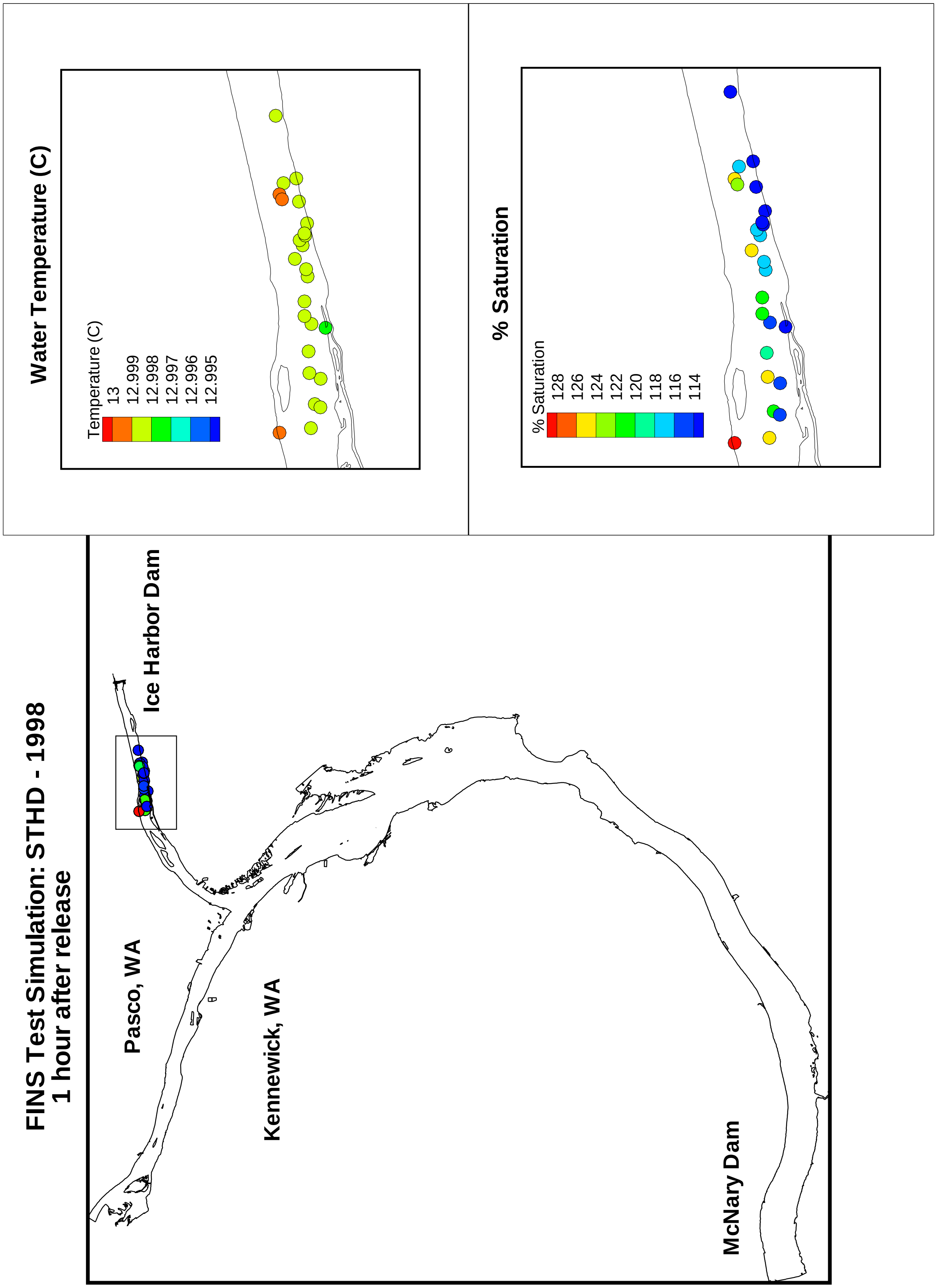

Figure 5.29: Location, local temperature, and total dissolved gas saturation levels of twenty simulated fish particles, 1 hour after relaease in the Ice Harbor tailrace. Fish movement parameters derived for hatchery Steelhead during the 1998 migration season were used

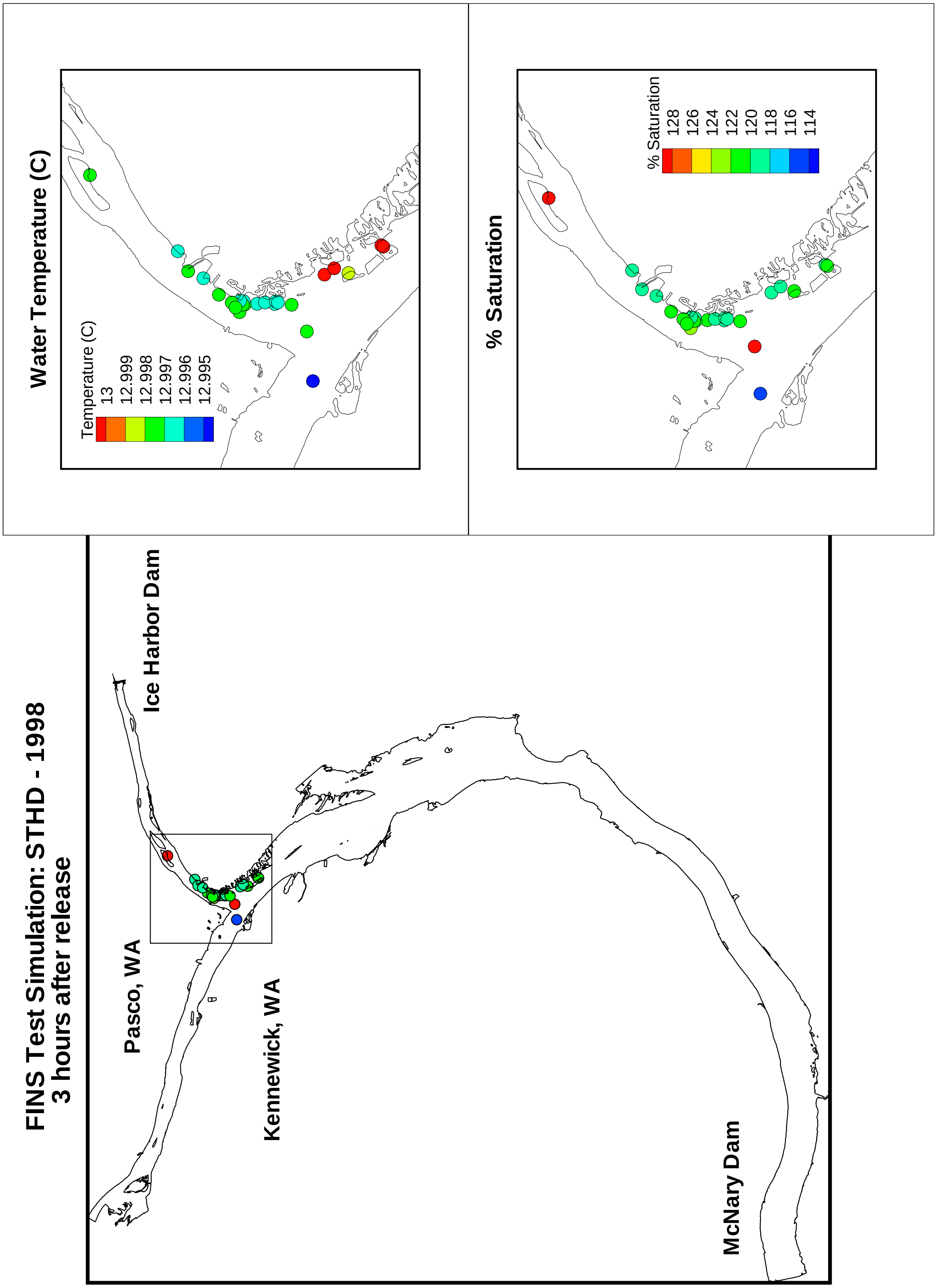

Figure 5.30: Location, local temperature, and total dissolved gas saturation levels of twenty simulated fish particles, 3 hours after relaease in the Ice Harbor tailrace. Fish movement parameters derived for hatchery Steelhead during the 1998 migration season were used

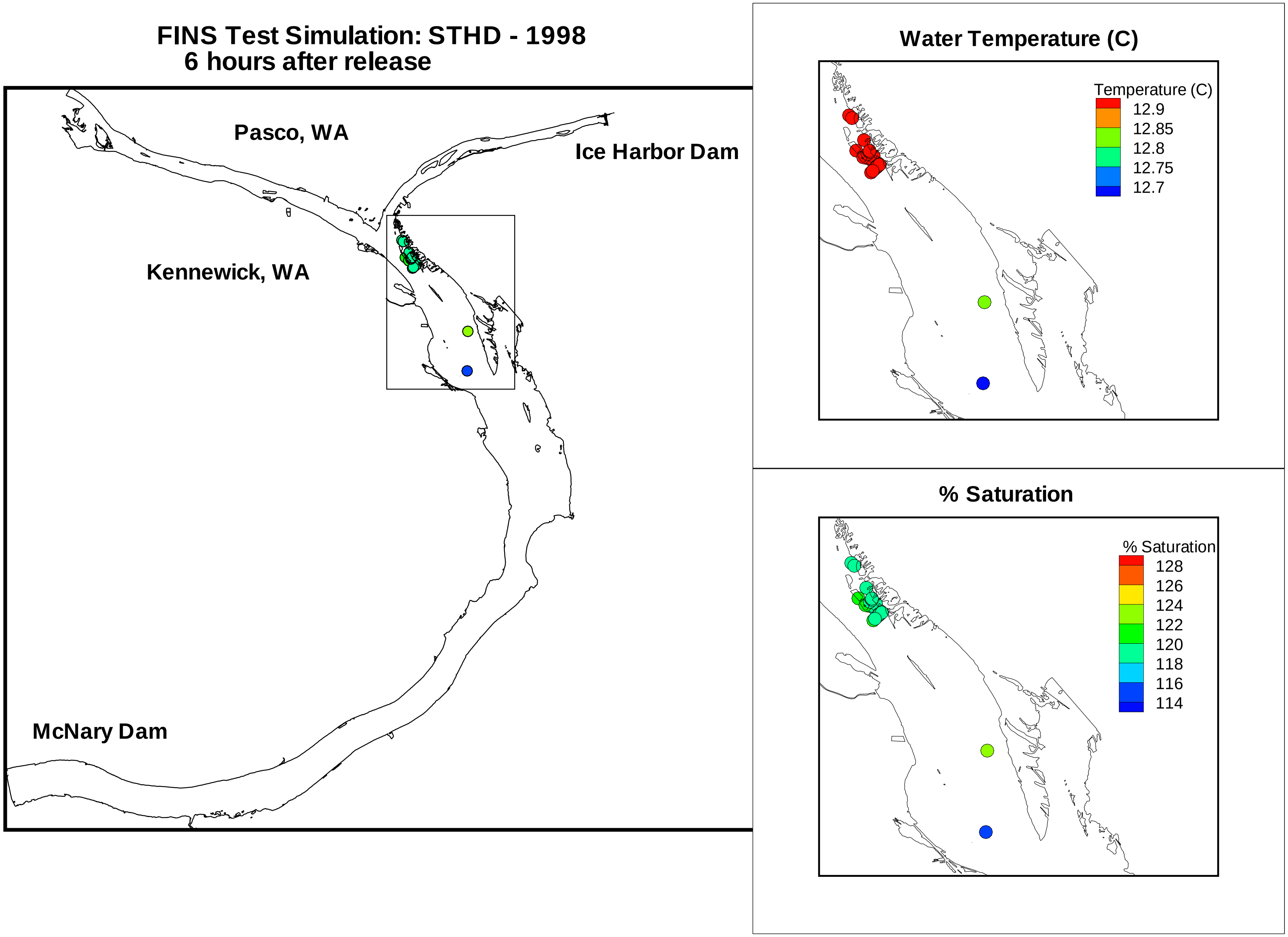

Figure 5.31: Location, local temperature, and total dissolved gas saturation levels of twenty simulated fish particles, 6 hours after relaease in the Ice Harbor tailrace. Fish movement parameters derived for hatchery Steelhead during the 1998 migration season were used

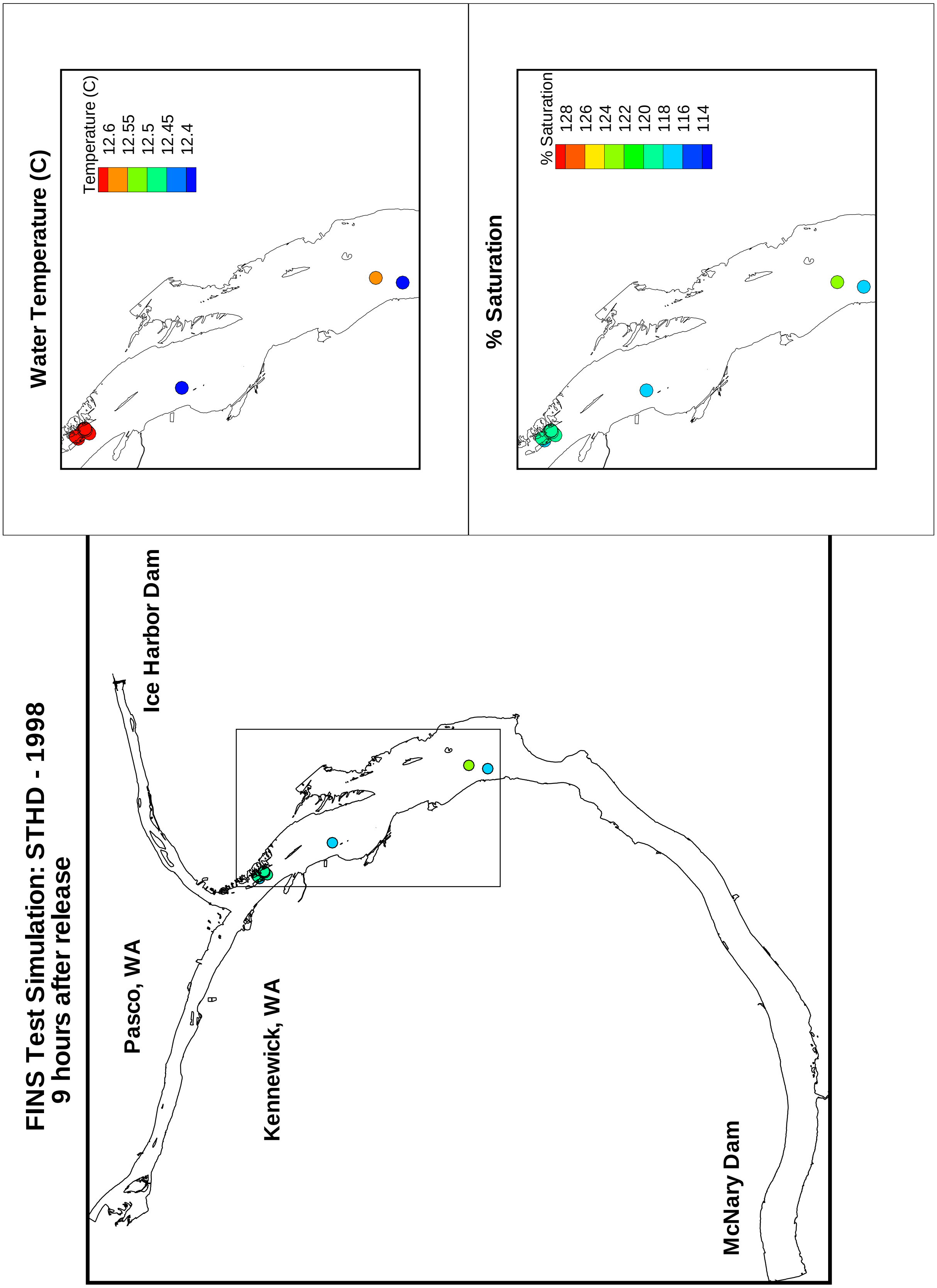

Figure 5.32: Location, local temperature, and total dissolved gas saturation levels of twenty simulated fish particles, 9 hours after relaease in the Ice Harbor tailrace. Fish movement parameters derived for hatchery Steelhead during the 1998 migration season were used

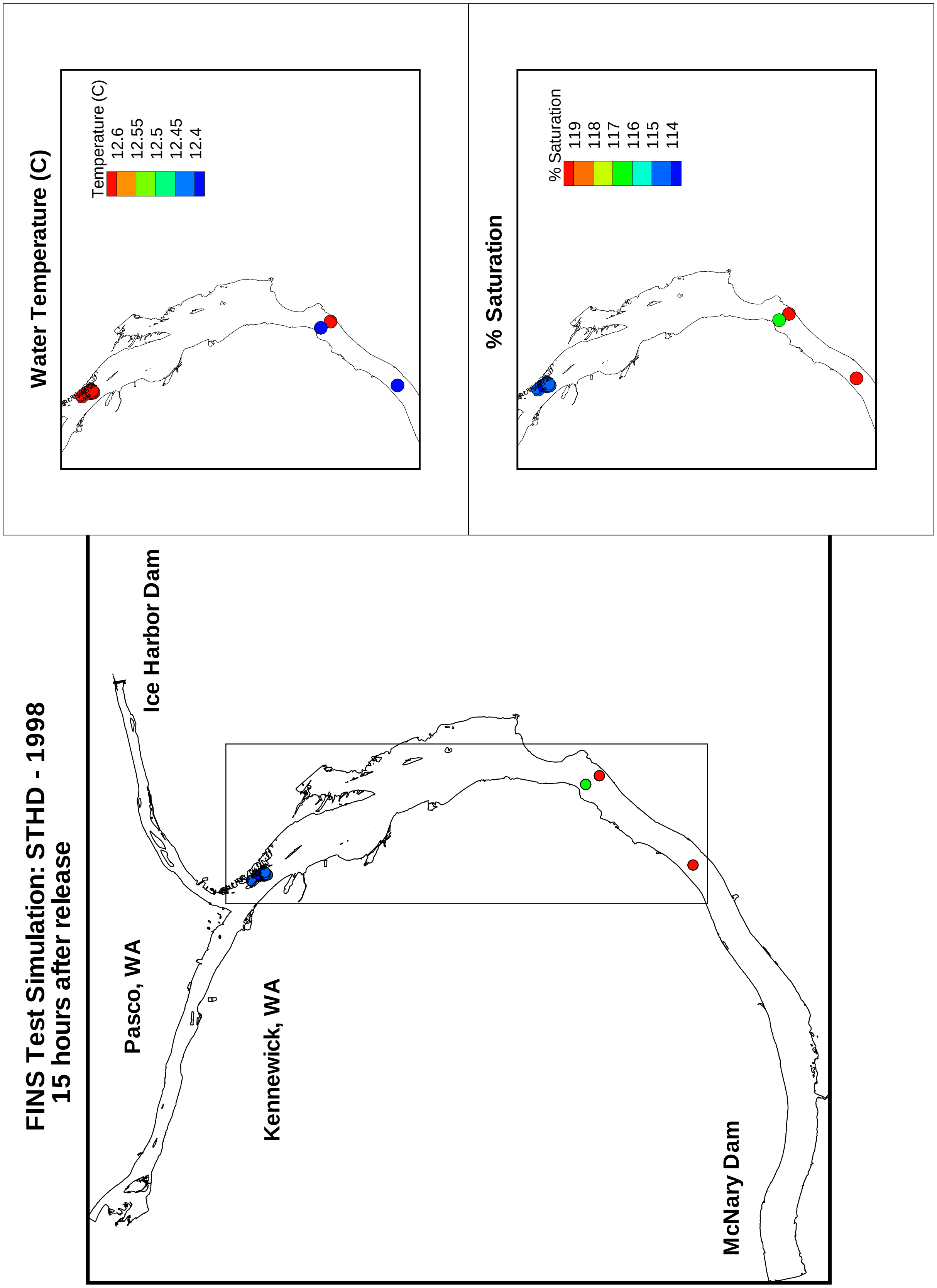

Figure 5.33: Location, local temperature, and total dissolved gas saturation levels of twenty simulated fish particles, 15 hours after relaease in the Ice Harbor tailrace. Fish movement parameters derived for hatchery Steelhead during the 1998 migration season were used

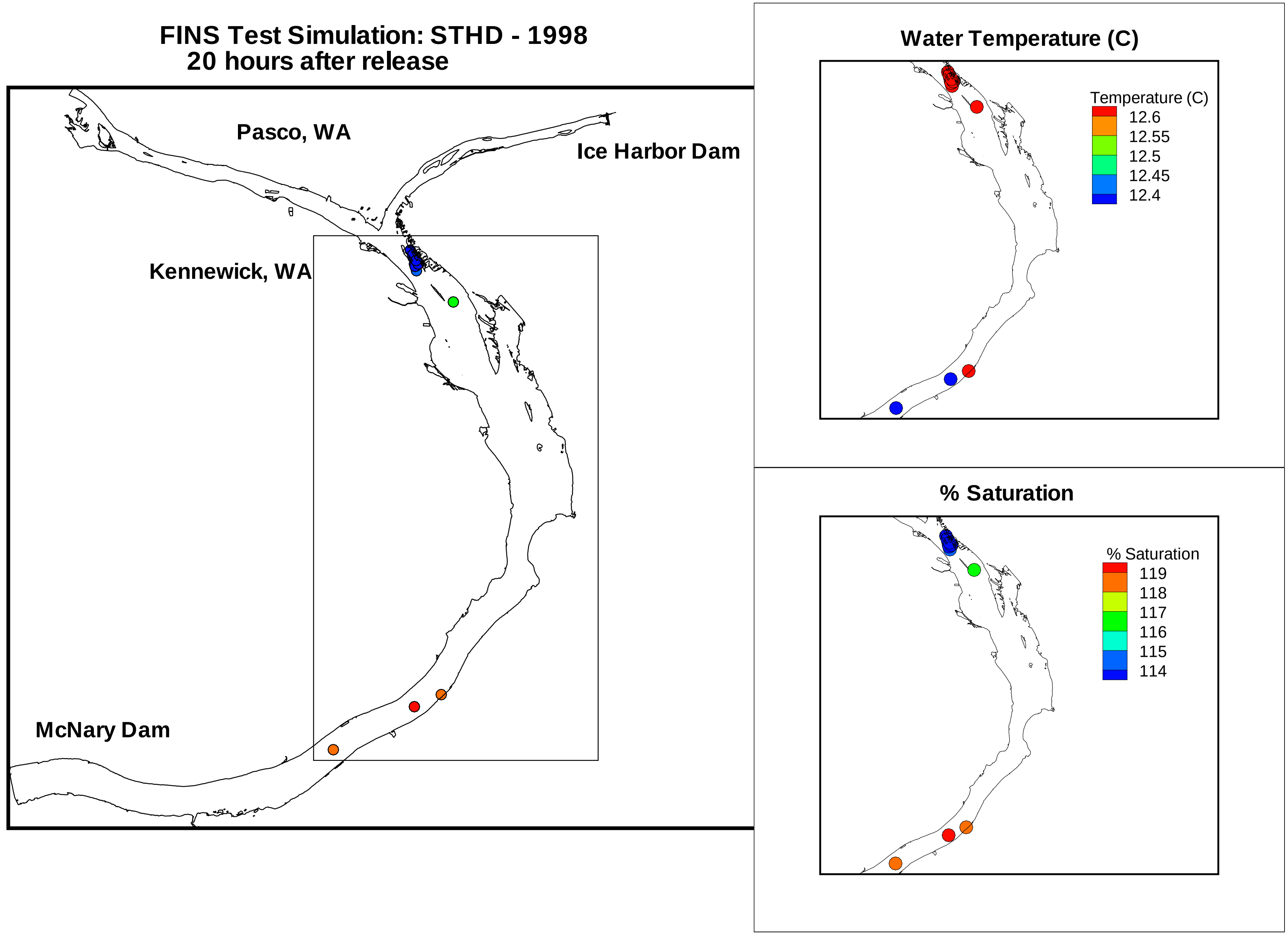

Figure 5.34: Location, local temperature, and total dissolved gas saturation levels of twenty simulated fish particles, 20 hours after relaease in the Ice Harbor tailrace. Fish movement parameters derived for hatchery Steelhead during the 1998 migration season were used

5.3 Example FINS Run with 1000 Particles

The example runs above used a small number of particles to facilitate graphical presentation and summary. However, FINS can be run with a much larger number of particles to create statistically valid numerical summaries of dissolved gas exposure levels. In this section, we present results of a FINS run performed using parameters for 1998 hatchery spring chinook (HSPC), the same as in section 4.3, case 2, but with 1000 simulated particles. FINS execution times using 1000 particles are not significantly greater than those using only 25 particles, since the large bulk of the execution time is allocated to file input (reading MASS2 velocity and concentration information). The primary computational constraint lies in the generation of long sequences of correlated random numbers using GSLIB; for 1000 particles, 24 hours, and a 50-second time step, approximately 1.8 million random numbers are required for each of the longitudinal and transverse components of dispersion. To ensure preservation of specified correlation at various distances, while limiting the number of data used in the stochastic simulation of each point, a nested simulation approach was used wherein the first simulation generated values on a coarse grid (observations separated by large times), a second round simulated values on an intermediate grid (with the coarse grid values as conditioning data), and the third round simulated values on the full-resolution grid (50-second time intervals) using both the coarse and intermediate-grid values as conditioning data. Execution times for 1000 particles (FINS and the supporting GSLIB runs) are on the order of thirty minutes or less, indicating that much larger runs could easily be performed.

The FINS output was processed using ”PostPro” to generate statistical summaries of individual and cohort depths and exposure levels.

Figure 5.35 shows histograms of average depth, dissolved gas, and temperature experienced by each of the 1000 simulated fish (averages are for individual fish over time).

Figure 5.36 shows histograms of the maximum and 90th percentile of dissolved gas exposure for individual fish. These indicate that most of the individual simulated fish experienced high dissolved gas levels (over 125 percent) at some time during the simulation period, but that only a relatively small percentage experienced DGAS levels greater than 125 percent for an extended time (ten percent of the simulation period).

Figure 5.37 below shows the average DGAS level experienced at each time step in the simulation period (time steps are 50 seconds in duration), averaged over all 1000 simulated fish particles. This plot indicates the large-scale trends in dissolved gas during the first three hours of the simulation period, and suggests that on average the highest levels of exposure exist in the tailrace of Ice Harbor Dam.

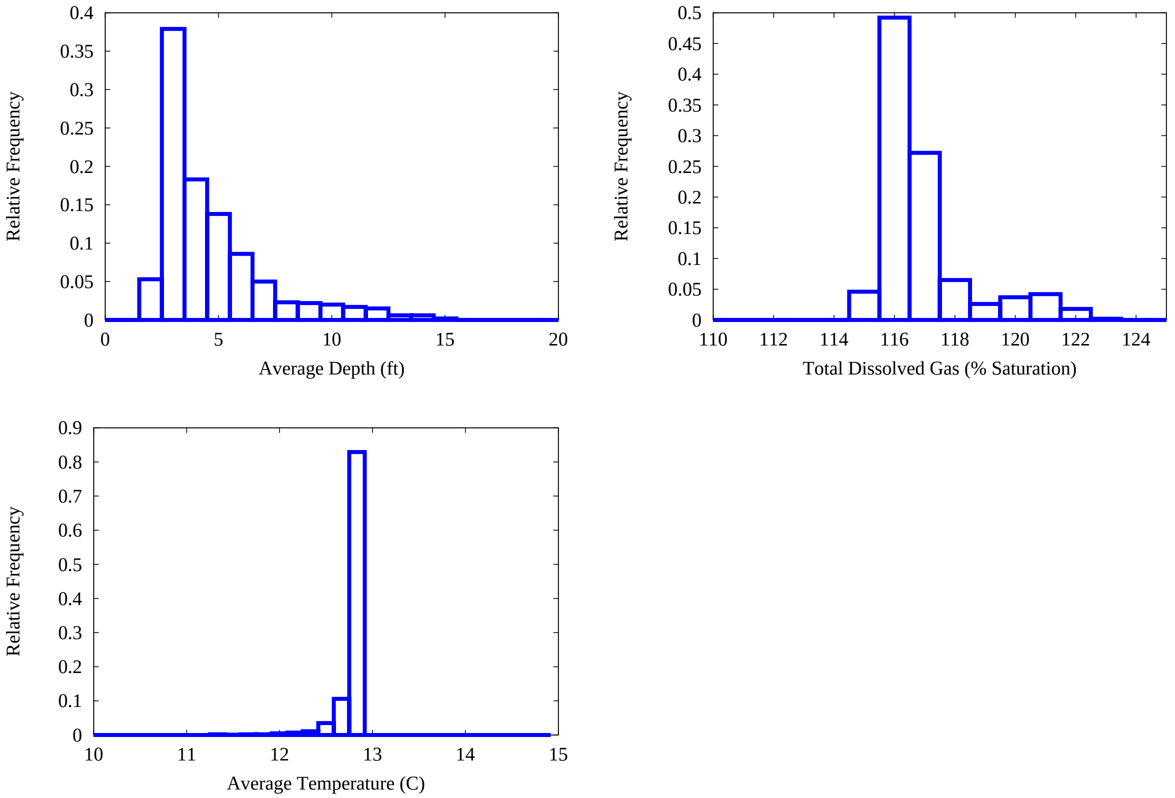

Figure 5.35: Histograms of average depth, dissolved gas, and temperature experienced by each simulated fish

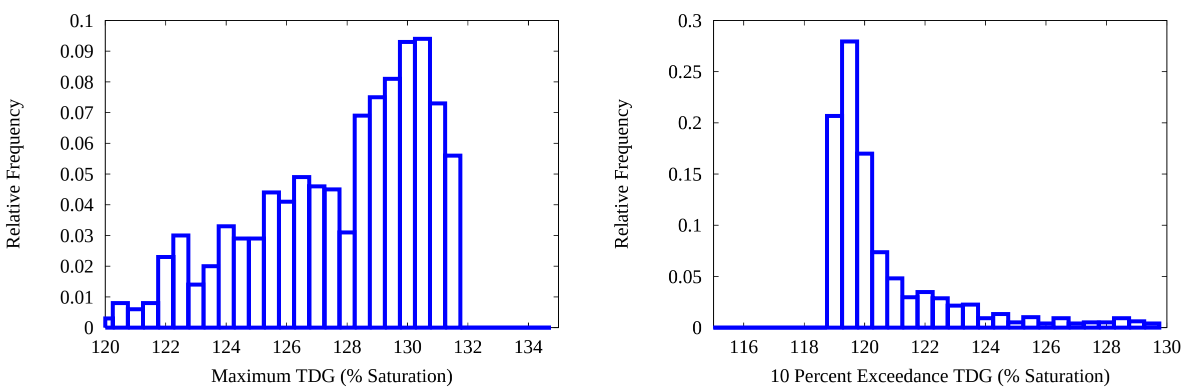

Figure 5.36: Histograms of the maximum and 10 percent exceedance level of dissolved gas exposure for individual fish

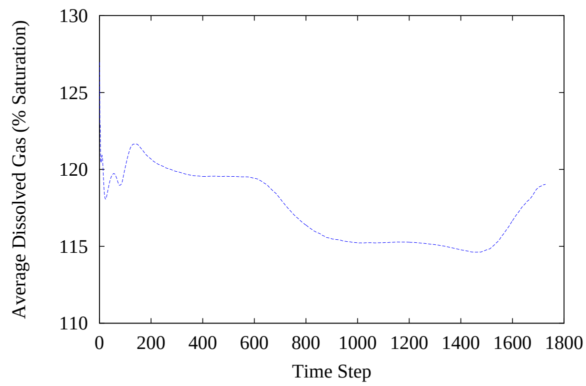

Figure 5.37: Average TDG level experienced at each time step in the simulation period

References

Anderson, J., Shaw, P., and Zabel, R. (1998). Crisp degas model progress report. Draft report, University of Washington, Seattle, WA 98195.

Beeman, J., Robinson, T., Haner, P., Vanderkooi, S., and Maule, A. (1998). Gas bubble disease monitoring and research of juvenile salmonids. Report, U. S. Geological Survey, Cook Washington for Bonneville Power Administration, Portland, Oregon. contract 96AI93279.

Payne, J. (1982). *Introduction to Simulation.* McGraw-Hill, New York, New York.

Zabel, R. (1994). Spatial and temporal models of migrating juvenile salmon with applications. Doctoral dissertation, University of Washington.

A Appendix A - FINS Version 1.06 Documentation

Fish Individual-based Numerical Simulator (FINS) Release 1.06 February 2000

A.1 Executable Files and Run Sequence

1. *fins_v106*: FINS particle tracking code, release version 1.06 (main program).

2. *initial*: Program for (optionally) generating initial fish locations and times, etc. (pre-processor).

3. *postpro*: Program for (optionally) creating summaries of individual and cohort averages of depth and dissolved gas exposure (post-processor).

All executables are compiled using FORTRAN 90 for the SGI Unix platform (they can be executed on ”mack.pnl.gov” or equivalent hardware) and require input both interactively from the user and in static files located in the same directory that the program is executed from. In general, ”initial” would be executed first to create the file of initial fish locations and times (although the file can be created by hand if preferred). The resulting output file would then be renamed and moved to the directory containing the other FINS input files, and finsv106 would be executed. The binary file gashist.dat created by fins_v106 would then be moved to the postpro directory and postpro would be executed to generate summary measures of fish exposure. Other utility scripts have also been created (both Unix shell or perl scripts, and TecPlot macros) that are used to generate graphical summaries of FINS model output such as presented in this report.

A.2 *initial* Input

A single input file (named srr.def) is required for initial. It must reside in the directory from which the executable file is run. It contains generic information regarding possible species for simulation and assigns a numerical flag to each species/run/rearing type class. This allows the capability (not currently fully used in the code) to assign different behavior characteristics (parameters) as a function of species. For the current example runs, srr.def will generally not require any changes. The basic format of the file is as shown below. The file can contain any number of different classes, each with a unique flag.

FLAG	SPECIES	RUN	REARING TYPE
1	Chinook	Spring	Hatchery
2	Steelhead	Summer	Hatchery
3	Steelhead	Summer	Wild
4	Chinook	Fall	Wild

All other input required for initial is provided interactively by the user at run time. The interactive input is fairly extensive; several options for initial fish distribution in plan view, depth, and time are provided. It allows the user to create up to 1000 individual fish, which can be composed of one or more release groups. Note that geometric coordinates are in terms of the rectilinear cartesian coordinate space normalized to width and length of 1.0 (dimensionless units), not actual river geometries. That is, an x- coordinate of 0.5 corresponds to the middle of the river, and a y-coordinate of 0.0 corresponds to the upstream end of the reach (y = 1.0 corresponds to the downstream end of the reach). ”Reach number” refers to the order of the grid files that define sub-reaches of each pool. For most of the example runs, fish will be released at the upstream end (y=0.0) of reach number 1, corresponding to the tailrace of the dam at the top of the modeled pool.

A.3 *initial* Output

Upon execution, initial creates a single output file (*fort.22*) that contains the initial number of fish, their release locations and times, species flags, etc. It is in the format required for input to FINS as the *fish.dat* file (see below). This file can be directly renamed to *fish.dat*, moved to the FINS executable directory, and used as input to*fins_v106* as is.

A.4 FINS v106 Input

fins_v106 requires the preparation of several input files that provide linkage to the hydrodynamic model, specify parameters, and control the overall simulation flow. Interactive input is limited, and consists only of responses necessary to continue execution at simulation breakpoints. The input files, their functions, and formats are described below. Examples of each file are provided in the release directory (subdirectory ”Example Input”). Unless otherwise specified, the filenames must follow the name conventions given in italics below.

fins.cfg

> Function: This is the primary configuration file that provides control over the simulation process (which processes and sub-models are to be implemented, time interval and time steps, number and names of grid files and hydrodynamic data files, etc.).
>
> Format: Free-format ASCII text. The contents and format are described in detail below. fins.cfg is generated/edited manually using any text editor.

fish.dat

> Function: This file provides the initial release locations and times for the fish particles.
>
> Format: Free-format ASCII text. The first line contains a single integer – the total number of fish particles. The second line contains the reference date/time string in the format ”mm-dd-yyyy hh:mm:ss”. The remainder of the lines (one per fish) are as follows:

xloci(i), yloci(i), timei(i), depthi(i),srrtype(i), smolti(i), ireach(i)
where
loci = initial normalized x-coordinate [0 to 1]
yloci = initial normalized y-coordinate [0 to 1]
timei = initial time (in hours from the reference time)
depthi = initial depth (feet)
srrtype = species flag (as defined in srr.def)
smolti = initial degree of smoltification (not currently used)
ireach = release reach number

fish.dat can be generated either using initial (see above) or manually using any text editor.

species.dat

<u>Function:</u> This file defines behavioral parameters for one or more fish species. Current sample runs will typically use one species only, although several species can be simulated in a single run.

<u>Format:</u> Free-format ASCII text. The first line contains a single integer – the number of species classes to be parameterized. For each species class, a set of ten input lines is required as shown in the example file below:

1	number of species defined
1	species flag
Chinook	
Spring	
Hatchery	
1.0 1.0	longitudinal and transverse dispersivities
1.0 1.0	x and y diffusion coefficients
0.00 0.0004	mean, variance of vertical velocity fluctuations
1.5 0.02	preferred depth, linear preference coeff.
1.5 1.0 2000.0	preferred depth, alpha, psi (expon. model)

Dispersivities are specified in units of feet, diffusion coefficients in units of ft2/sec, velocities in ft/sec, and depths in feet. Alpha, psi, and the linear preference coefficient are non-dimensional. The species flag refers to the definitions used in *srr.def* and *fish.dat*. *Species.dat* must be created/modified manually using a text editor.

weather.dat

<u>Function:</u> This file specifies weather conditions (especially barometric pressure) that are used in the gas conversion functions to compute ”delta-P”.

<u>Format:</u> The file consists of a series of lines, each corresponding to a discrete time. Conditions are linearly interpolated between the specified time points. The specified time points should include the time interval being simulated. This file uses the same format as that used in the hydrodynamic

simulation, and can be directly used from the corresponding MASS2 run. An example file is shown below; this example specifies constant meteorological conditions between 6:00 pm May 28 and 6:00 am June 2, 1996.

05-28-1996 18:00:00 25.0 16.7 3.0 760.0 145.26 /
06-02-1996 06:00:00 25.0 16.7 3.0 760.0 145.26 /

bcspecs.dat

Function: This file is used to specify the connections between reaches within the subject pool, and the types of boundaries.

Format: The format is the same as used in MASS2 hydrodynamic simulation, and can be used directly as is.

1 US TABLE FLUX PART ”BC Files/JDA_QS.prn” 1 10 /
1 US TABLE FLUX PART ”BC Files/JDA_QP.prn” 11 24 /
1 DS BLOCK ELEV PART 2 1 9 /
1 DS BLOCK ELEV PART 3 10 24 /
2 US BLOCK VELO ALL 1 /
2 DS BLOCK ELEV ALL 4 /
3 US BLOCK VELO ALL 1 /
3 DS BLOCK ELEV ALL 4 /
.
.
.
10 US BLOCK VELO PART 9 16 24 /
10 DS TABLE ELEV ALL ”BC Files/TDA_FBZ.prn” /

Note that the BC files specified in *bcspecs.dat* are not actually used in FINS (only in MASS2), so these files are not required to be in the run directory for execution of FINS.

Hotstart Files (several):

One or more ”hotstart” files are required to provide the hydrodynamic and mass transport input for FINS (flow velocities, dissolved gas concentrations, temperature, etc.). These files are in the standard binary format written out by MASS2, and represent snapshots of river conditions at specified discrete times. Velocities and transported constituent concentrations at intervening times are represented in FINS by linear interpolation between the hotstart data. FINS stores in memory only two hotstart files at any given time for the interpolation endpoints, and reads new data into memory as needed as the simulation progresses through time. Any number of hotstart files can be provided. The number of hotstart files, their names, and associated date/time strings must be specified in the fins.cfg file. If only one hotstart file is to be used (representing a simulation under steady state river conditions), then the number of hotstart files should be specified as ”2” and the same filename given twice with two different times corresponding to the beginning and end of the simulation.

Grid Files (several):

One or more grid files, containing the descriptions of the numerical grids used to represent the river geometry in plan view, must be placed in the run directory. These files are exactly the same ones used in the MASS2 run, and should be used as is. The number of grid files, their sequence, and their names are specified in the fins.cfg file.

A.5 FINS_v106 Output

The output from fins_v106 is written to several files (as well as some interactive output to the terminal to allow the user to track simulation progress during the run). Example output files are available in the release directory (subdirectory ”Example Output”). The output files and their contents are described below:

fort.13, fort.14

These two files contain general execution tracking messages related to the progress of the simulation, and will usually only be needed if some run-time problem is encountered.

fort.17

This file contains warning messages regarding array indexing and boundary reflections, and is generally only needed for debugging purposes.

fort.30

Contains arrival time information for each fish that has transported through the entire pool to the forebay of the downstream dam. ASCII format, first column is fish number (integer), second column is travel time from release point to dam forebay in hours (floating point).

fishout.dat

Contains final locations and times of all fish at the end of the simulation. This file has the same format as *fish.dat*, and can be used as an input file to restart/continue the simulation.

locations.dat

Contains information on the spatial coordinates and dissolved gas levels of each fish particle at user-specified time intervals during the simulation. The file is in ASCII format and contains four columns. The first column is time step number (integer), second and third columns are x and y coordinates of the particle respectively (state-plane coordinates in feet, floating point), and the fourth column is the total dissolved gas concentration (mg/L, floating point). Note that once a fish has reached the downstream end of the pool, the dissolved gas concentration will register as zero in this file. The time interval for printing fish locations (in terms of number of time steps between printing) is specified in the *fins.cfg* input file.

gashist.dat

Contains temperature, depth, and gas exposure history logs for each fish, written at all time steps. File format is ASCII, comma-separated. The first record contains the number of fish and the number of time steps. The remaining records contain dissolved gas (mg/L), depth (ft), and temperature (oC) for each fish at each time step. This file is used as input for the post-processing module (PostPro). Note that this file can be quite large (for example, 80 Mb for a run using 1000 fish and over 3500 time steps).

fins_tecplot.dat

This file contains the location and dissolved gas levels experienced by each fish particle. It is in a standard ASCII format required for input to TecPlot graphics macro routines. The variables in each column are defined in the file itself, as is the time interval at which printouts are made. This file is printed at the same interval as *locations.dat*, which is controlled by a variable (number of time steps between print intervals) in *fins.cfg*.

A.6 PostPro Input:

The input for postpro consists of two files: 1) a binary data file (output from FINS, gashist.dat), and 2) a configuration file. The function and format of these two files is described below:

pp.cfg

This configuration file, in ASCII format, controls the execution of PostPro. It can be created/modified using any text editor. An example configuration file is shown here:

```
PostPro 1.1 Configuration File
gashist.dat
1 1 0 0
average.dat
indiv.dat
indiv_quant.dat
5
```

The first line is a title (up to 80 characters). The second line is the name of the input binary file (usually gashist.dat). The third line contains four flags the type of output desired. The first flag (if set to 1) will cause ensemble (cohort) averages (averages over all fish, computed at each time step) to be computed and output. The second flag (if set to 1) will cause individual summaries (summaries for individual fish computed over all time steps) to be computed. The third and fourth flags, if set to 1, will cause individual depth and dissolved gas profiles (respectively) to be printed to output files fort.23 and fort.27. Any or all four of these functions can be turned off by setting the flag to 0. The next three lines are the names of output files, the first for ensemble measures, the second for averages over all times steps for each fish, and the third for exposure quantiles. These output filenames must be specified even if the corresponding computation is turned off (flag set to 0). The final line contains a flag denoting which dissolved gas measure should be computed and printed to the output files. Constant barometric pressure of 760 mm Hg is assumed.

! gas_flag specifies which measure of dissolved gas is to
! be printed:
! 1 = TDG in mg/L
! 2 = Gas saturation in ! 3 = Total gas pressure (mm Hg)
! 4 = Delta(gas pressure) (mm Hg) - relative to atmospheric
! 5 = Depth-compensated DeltaP (mm Hg)

gashist.dat

This file is an ASCII file containing the results generated by a FINS run. See the description under the FINS Output section above.

A.7 PostPro Output:

The output from PostPro consists of three files containing summary measures of fish exposure to gas and temperature, and fish depth. These files are in columnar ASCII format, with header lines that describe the contents of the columns.

A.8 FINS Configuration File Format (fins.cfg):

The file *fins.cfg* controls the program execution, specifies names of input files and grid files, and provides some parameters for fish transport processes. The required entries in this file and their format are described in this section. In general, *fins.cfg* is a free-format ASCII file composed of multiple lines in a specific order.

The first two lines contain a descriptive title (text, both lines up to 80 characters each). The third line contains a single integer value, the number of grid ”blocks” (e.g., subreaches within the pool numerical grid structure). This number is equal to the number of grid files to be read into FINS, and must be consistent with the value used in the corresponding MASS2 runs. The fourth line contains a single integer value, the maximum number of chemical species. This line must be the same as the value used in the MASS2 configuration file in order to properly read in the binary hotstart files, so the user should have available a copy of the configuration file used in the corresponding MASS2 runs to work from. The fifth line contains a single integer, the number of hotstart files (from MASS2) to be read in. The next several lines (one for each hotstart file; there must be at least two) contain the filenames and date/time strings for each hotstart file, in order of increasing time. The format of each line is as shown below:

hotstart_05-28-1996_180000.bin 05-28-1996 18:00:00

where the first column is the name of the file, the second column is the date (mm-dd-yyyy format), and the third column is the time (hh:mm:ss format). Following the list of hotstart files are several lines containing the names of the grid files in proper order (order corresponds to the numbering in the bcspecs.dat file, with grid number 1 first). The number of grid file lines (one per grid file) is as specified in line 3 as described above. Each line simply contains one entry, the name of the grid file. Following the list of grid files are two lines containing the beginning and end time of the FINS simulation. Each of these two lines contains a single date/time string in the format "mm-dd-yyyy hh:mm:ss" (e.g., 05-28-1996 18:00:00), with the beginning time first and the ending time in the second line. The next line contains a single number, the length of the desired time step in seconds. Following the time step is a line containing the print interval, an integer number describing the number of time steps between printing data to the files locations.dat and fins_tecplot.dat . For example, for a time step of 50 seconds, a print interval of "72" corresponds to printout every hour (50*72 = 3600 seconds = 1 hour) of simulated time. The next five lines contain the filenames of selected input and output files. Default filenames are as listed above (*locations.dat*, *gashist.dat*, *weather.dat*, *fish.dat*, and *species.dat* in order, one filename per line), but other names can be substituted if desired. These lines are followed by a line containing two integers; the first is a random seed value (arbitrary between 1000 and 99999) used to seed the random number generator, and the second is a flag specifying whether the random numbers are to be written to file or not (generally they will not be unless debugging or testing the random number generator). A value of "0" is used to specify that the random numbers not be written to file; a value of "1" will cause a list of random numbers to be written to fort.31 . The next line contains three integer flags (0 for "off", 1 for "on") that specify which transport processes are to be applied. The first flag is for advection, second is for dispersion/diffusion, and the third is for correlated random walk. Any combination of the three is possible, although generally the advection flag will be turned on (value of "1"). The last line contains three integer flags (0 for "off", 1 for "on") that specify the method used to model fish depth variations. The first flag represents the linear depth preference function, the second the exponential depth preference function, and the third the random vertical velocity function. Most example runs have used a combination of one and three (random vertical velocities with linear depth preference).